THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME VIII DECEMBER 1898 NUMBER 5

THE PROBABLE RANGE OF TEMPERATURE ON THE MOON. II.

By FRANK W. VERY.

THE opinions which have been hazarded concerning the lunar surface temperature cover an extraordinary range. We find suggestions of something approaching a red-hot state in the middle of the lunar day, or to quote Sir John Herschel's most conservative statement, we learn that "the surface of the full Moon exposed to us must necessarily be very much heated,—*possibly* to a degree much exceeding that of boiling water;" and on the other hand, Ericsson concluded in favor of "perpetual intense cold," and a temperature about 80° F. above absolute zero under full sunshine.

Something of this uncertainty still lingers in even our best text-books. There are few works on astronomy more thoroughly reliable than Professor Young's; but his statements on this subject, while holding a middle ground, are still unsatisfactory; and his conclusion that "it now seems rather more probable that the temperature never rises above the freezing point of water," because measures in the infra-red spectrum of the Moon show "the presence in the lunar radiations of a considerable quantity of (radiant) heat which has a wave-length greater

than that radiated from a block of ice, and is, therefore, probably radiated from something colder than ice," by no means follows, since the point of maximum radiation in the spectrum has been displaced by atmospheric absorption. By choosing radiations on which our atmosphere exercises little absorption, and using only such in the comparison, it can be shown that the effective radiating power of the sunlit Moon is certainly much above that of ice; and any reasonable restoration of the spectral energy curve of the Moon, with allowance for atmospheric absorption, will lead to the same result.

Before proceeding to other evidence in this line, I will describe an experiment designed as a test of the lunar glaciation theories of Ericsson and Peal.

With apparatus arranged for thermal measures in the lunar image, a concave mirror receiving rays from a siderostat and concentrating them on the bolometer, I replaced the siderostat mirror by a surface of snow, and in full sunshine with a clear sky, between 1^h and 2^h P.M., exposed the bolometer to the radiation of sunlit snow by withdrawing a black copper screen placed between the snow and the concave mirror. The angular aperture of the bolometer being but a small part of that of the Moon, the observation amounts to one in the image of a virtual snow Moon, since it is a matter of indifference whether the reflecting surface is inside or outside the Earth's atmosphere, the absorption being the same in either case.

The progressive increase of glass transmission is probably due to increasing depth of water from melted snow, accumulating in the interstices, and coating the ice-particles, thus depleting the solar rays passing through the water of those longer waves not transmitted by glass, in consequence of which the reflected sunbeam, more deficient in these long waves than at the outset, is more readily transmitted by glass.

The surface of the snow was then sprinkled with lampblack, but the wind blew so much of the light carbon away that the resulting surface was not dead black, but gray. The result was a diminution of the reflection from an intensity of 95 to 29; but

the transmission by glass (0.803) remained scarcely changed from the previous final measurement.

TABLE VI.

Temperature of exposing screen, - - - - - - - - - = +5°.3C.
Temperature of room, - - - - - - - - - = +5°.1
Outside temperature, - - - - - - - - - = −7°.0
Snow, at first dry, soon melting in the sunshine.

Radiation from pure white snow, in sunshine	Same through glass	Transmission by glass
div.	div.	
84, 98 } 91.0		
	75, 63.5 } 69.3	$\frac{69.3}{95.3} = 0.727$
99, 100 } 99.5	} 72.3	$\frac{72.3}{99.5} = 0.727$
	75, 75.5 } 75.3	$\frac{75.3}{97.8} = 0.770$
96, 96 } 96.0	} 76.8	$\frac{76.8}{96.0} = 0.800$
	79.5, 77 } 78.3	$\frac{78.3}{94.3} = 0.830$
94, 91 } 92.5	} 77.8	$\frac{77.8}{92.5} = 0.841$
	76, 78.5 } 77.3	$\frac{77.3}{93.8} = 0.824$
93.5, 96.5 } 95.0	} 76.6	$\frac{76.6}{95.0} = 0.806$
	76.5, 75 } 75.8	Mean. - 0.791

A concluding measure on fresh white snow in shade gave a negative reading of $-5^{\text{div}}.3$.

It appears from the first series (Table VI) that the solar radiation, reflected from white snow, gives a deflection of about 100 divisions, which is very nearly the same as that produced

with this apparatus by the hottest parts of the Moon when compared with the neighboring sky. Instead, however, of transmitting only 12 to 17 per cent. of this radiation, the same glass which allows this fraction of the lunar rays to pass, transmits from 73 to 84 per cent. of the reflection from white snow.

This experiment alone throws considerable doubt on Mr. Peal's supposition of a lunar surface largely composed of ice and snow, in which circular Maria and walled plains have been melted out by local sources of heat. But it is urged by Mr. Peal that the ancient lunar snows have become darkened by meteoric dust. The second part of the experiment answers the question whether a deposit of some sort of dust could so change the reflecting power of snow as to enable the radiation from it to approach in quality that from the Moon. The answer is that when snow is blackened until its reflective power is less than 30 per cent. of that of pure white snow, the reflected solar beam still has identically the same transmission by glass (about 80 per cent.) in either case. We might imagine the meteoric dust to have peculiar reflecting power, but unless the layer were of considerable depth (which I understand is not Mr. Peal's supposition), the character of the radiation could hardly suffer so extraordinary a change from a mere surface deposit of dust, and further facts, yet to be adduced, are conclusive against a day temperature on the Moon consistent with glacial formations.

Ericsson's estimate of a lunar day temperature about 45° C. above absolute zero, rests upon his claim "that the previous temperature of a body exposed to the Sun's radiant heat is immaterial," and that the excess of temperature imparted by the Sun's rays will be the same for a body at the absolute zero as for one already several hundred degrees hotter. (See *Nature*, **34**, 250, 1886.) As no figures are given to support this assertion, it may be said in contradiction that experimental results decide otherwise. For example, Violle obtained constantly diminishing excesses of his Sun thermometer, when the temperature of the enclosing water jacket of his actinometer was raised.

Temperature of water jacket	Excess of Sun thermometer
99°.35	10°.75
107 .4	9 .55
116 .15	9. 25
136 .5	8. 22

The failure to recognize the distinction between radiant power and temperature is responsible for many of the misconceptions connected with this subject. Ericsson would have said that a body at 400° radiates twice as much as one at 200°. Actually these relations are sustained by bodies at 400° and 323° absolute temperature.

I now pass to the measures of lunar radiation contained in my essay on the *Distribution of the Moon's Heat*, published by the Utrecht Society of Arts and Sciences. I have several times been asked by meteorologists and astronomers to give an interpretation of these measures, translating the arbitrary values into thermometric degrees. The desirability of this translation is evident, and the preceding studies of the first part were undertaken in order to approach the subject from the experimental side.

The most modern measures indicate values for the absolute constants of radiation at the freezing point about half as great as those which Pouillet surmised from the experiments of Dulong and Petit. The curve of absolute radiation of lampblack on metal, adopted in this research, rests partly on the measurements of Dr. J. T. Bottomley on the absolute emissivity of sooted copper, and partly on astrophysical considerations which will be described at length in a special paper. The following table gives the adopted values of absolute radiation from the standard surface, in C. G. S. units (see p. 271), for temperatures on the absolute Centigrade scale, derived from this curve.

With the help of this table I can state that—the concave mirror of $721.066^{\text{sq cm}}$ area occupying $\frac{1}{867}$ of the hemisphere, and the bolometer of some $19^{\text{sq mm}}$ area, slightly cut down by the

diaphragm at the corners to a working aperture of 0.178$^{sq\ cm}$, filling 0.000000288 of a hemisphere at the mirror's focal distance—a deflection of one standard millimeter division of the galvanometer in my measures, represents an actual energy received by the bolometer, corresponding in thermal measure to 0.0000000396 small calories per second (about four one-hundred millionths of a small calory per second). But there is no need of using this constant, except for comparisons of instrumental sensitiveness, and it will be more instructive to state the results of the measurements of lunar surface radiation in terms of the radiation from unit surface of sooted copper to a hemisphere.

TABLE B.

Temperature	Radiation	Temperature	Radiation	Temperature	Radiation
25°	0.0002	200°	0.0033	375°	0.0204
50	0.0004	225	0.0044	400	0.0251
75	0.0006	250	0.0058	425	0.0307
100	0.0009	275	0.0076	450	0.0373
125	0.0013	300	0.0099	475	0.0452
150	0.0018	325	0.0129	500	0.0544
175	0.0024	350	0.0164	525	0.0650

The assumption has been made that radiation from unit angular area of a plane surface is equal in all directions, which is not quite true, especially at low angles, and for polished surfaces of particular substances, but for lampblack the assumed equality is nearly fulfilled.

Much vagueness, and no little misconception exists in writings on radiation through the lack of a consistent nomenclature. Dr. J. T. Bottomley has been very explicit in his description of radiant quantities, and in view of the prevalent looseness of expression, it may be well, in order to fix ideas, to speak, as he does, of radiation as measured in *gram-water-degree-Centigrade units of heat lost per square centimeter per second per degree Centigrade of excess of temperature;* but this mode of speech, though precise, is exceedingly cumbersome, and indeed intolerable, if it is to be often repeated; and I have therefore ventured to introduce a

new term: *radim*, from *radius*, a ray, and the root *im* = image or picture, a unit of radiation, representing a unit quantity of heat, namely one gram-water-degree-Centigrade heat-unit, lost *as radiation* per square centimeter of surface per second of time, by a heated body, or transmitted by the ether as an equivalent amount of radiant energy through a normal section of 1 sq. cm. in 1 sec. of time. The term is to be distinguished from the unit of absolute emissivity which includes: (*a*) the quantity of heat lost by radiation from a heated body, measured as *radiant emissivity* in radims per degree of difference between its temperature and that of the walls of the enclosure; as well as (*b*) the further quantity of heat transferred by convection and penetration to the surrounding fluid, and eventually imparted to the solid enclosing walls by conduction. This is the *convective emissivity* to be measured either in heat-units lost per sq. cm. per sec. per deg. Centigrade excess, or, if desired, in equivalent radims per deg. Centigrade of excess. It ought, however, to be clearly distinguished from component *a*, since it continues to exist, during the state of transference, as molecular thermal motion, and is propagated at a vastly slower speed, while it follows altogether different laws. I trust that the use of this new term may be pardoned in view of its saving of words.

In reducing my lunar observations, temperatures will be stated in absolute Centigrade degrees, and the corresponding radiations to absolute zero in radims. The value of one division of the galvanometer in radims, at the time of these observations, is obtained from measurements on blackened screens. For example, on January 12, 1889, screens at $+52^{\circ}.0$ C. $= 325^{\circ}.0$ Absol. and $+9^{\circ}.7$ C. $= 282^{\circ}.7$ Absol., gave the differential deflection $24^{div}.0$. The corresponding differential radiation to a hemisphere is

$$0.0129 - 0.0084 = 0.0045 \text{ radim.}$$

On this night, the factor reducing to standard instrumental conditions, which is needed for comparing observations on different dates, was 0.982, so that the $24^{div}.0$ represent 23.6 standard divisions, and one standard division represents

$$0.0045 \div 23.6 = 0.000191 \text{ radim}$$

to the hemisphere.

The average sky deflection in the vicinity of the Moon on this night was:

$$22.0 \times 0.982 = 21^{\text{div}}.6 = 0.00413 \text{ radim.}$$

The absolute radiation of the sky was

$$0.0081 - 0.00413 = 0.00397 \text{ radim}$$

the corresponding temperature of the comparison screen being $+7°.7$ C. $= 280°.7$ Absol.; and the effective temperature of the sky at the mean altitude of the Moon ($66° 36'$), taken from the new curve (or from Table B), is $214°$ Absol. $= -59°$ C.

For the actual observations and the first steps in their reduction, reference must be made to the paper cited, where, for comparison of observations made on the same night with various altitudes of the Moon, all galvanometer deflections from the Moon, relatively to the sky, are reduced to the zenith. The factors for this reduction were originally obtained by observation of the apparent transmission of the total moonbeam by the atmosphere, which was found to agree so closely with the apparent transmission of visual rays that no distinction need be made. Let it be well understood that this operation merely corrects for the variation in the apparent transmission of the already sifted moonbeam. The correction for the real absorption by an entire atmosphere, has still to be applied to each reduced zenithal deflection. The reduction to zenith is not made on the sky deflections. Each observation is a differential one, the standards being blackened screens from which an effective temperature of the sky is inferred and made the final datum-level for the night in question. This virtual sky temperature varies greatly from night to night, and from horizon to zenith. It depends upon atmospheric absorption of the bolometer's radiation towards outer space; but for a given set of observations the variation has not been large in any case, and the virtual sky temperature may be classed with instrumental constants in the present reduction.

Table VII gives measurements of radiation with inferred effective temperatures for limited regions of the Moon, made January 12, 1889 when the Moon's age was 11.2 days. They favor those regions where the angle of incidence of the solar rays is large.

TABLE VII.

January 12, 1889.			Moon's Age, 11.2 days.		
No.	Zenithal Deflection	Differential Radiation	True Emission	t	i
	div.	radim	radim		
1	85.7	0.01637	0.02865	416°	7°
2	59.7	0.01140	0.01995	372	47
3	27.4	0.00523	0.00915	292	74
4	56.8	0.01085	0.01899	366	70
5	58.7	0.01121	0.01962	370	70
7	32.3	0.00617	0.01080	308	74
8	33.9	0.00647	0.01132	312	74
9	74.7	0.01427	0.02497	400	35
10	64.7	0.01236	0.02163	382	35
11	77.7	0.01484	0.02597	404	22
12	82.6	0.01578	0.02762	412	10
13	76.7	0.01465	0.02564	403	32
14	72.7	0.01389	0.02431	396	37
15	86.6	0.01654	0.02895	418	7
16	82.6	0.01578	0.02762	412	17
17	78.7	0.01503	0.02630	406	18
18	81.6	0.01559	0.02728	411	17
19	54.8	0.01047	0.01832	362	70
20	54.8	0.01047	0.01832	362	70
21	36.8	0.00703	0.01230	321	66

Table VIII is for the full Moon, April 15, 1889, and favors those regions of maximum radiant power, over which the Sun is shining nearly vertically.

The first column contains a reference number which, with the date, identifies the observation. The second column gives the average radiation from a special region of the Moon, referred to the neighboring sky, and stated in galvanometer divisions, reduced to the standard instrumental condition, and corrected for the variation of atmospheric absorption which results from changing altitude, each observation being reduced to the value which might be expected after the rays have passed normally through an

atmosphere of average composition and 760^{mm} pressure. The third column gives the excess of radiation over that of the sky in absolute measure, and is obtained by multiplying the galvanometer deflection by the constant, $1^{div} = 0.000191$ radim. The fourth column is obtained by multiplying the third by 1.75, and refers the lunar radiation to that of a comparison surface at absolute zero with abstraction of intervening atmosphere, and at the same time eliminates that portion which is simply reflected solar radiation. The factor, 1.75, is an approximate average value whose derivation is given below (p. 275). The column headed t in Tables VII and VIII, gives the temperature of the lunar surface at the angle i from the subsolar point, and is inferred from the curve of absolute radiation for blackened copper (Table B, p. 270). This curve has been obtained by a combination of physical and astrophysical methods whose description I must defer. It is sufficient to say that it has responded very satisfactorily to a variety of tests, and is believed to be a close approximation to the truth.

TABLE VIII.

April 15, 1889.			Moon's Age, 15.7 days.		
No.	Zenithal Deflection	Differential Radiation	True Emission	t	i
	div.	radim	radim		
1	113.3	0.02164	0.03787	452°	7°
2	91.5	0.01748	0.03059	425	49
3	84.2	0.01608	0.02814	414	57
5	93.6	0.01788	0.03129	427	53
6	104.0	0.01986	0.03476	441	26
7	114.4	0.02185	0.03824	453	20
8	110.2	0.02105	0.03684	448	36
9	95.9	0.01832	0.03206	430	53
10	102.0	0.01948	0.03409	438	31
11	102.0	0.01948	0.03409	438	33
12	110.2	0.02105	0.03684	448	34
13	112.3	0.02145	0.03754	451	13
14	89.7	0.01713	0.02998	422	57
15	93.8	0.01792	0.03136	427	57
16	88.7	0.01694	0.02965	421	49
17	95.9	0.01832	0.03206	430	49
18	94.8	0.01811	0.03169	429	49
19	116.4	0.02223	0.03890	455	7

The derivation of the factor for reflection at the lunar surface and absorption by the Earth's atmosphere shall now be given.

Observations of the transmission of the moonbeam by glass enable us to distinguish very closely between the reflected and emitted portions. My measures were made in winter and early spring, and winter measures give a ratio of lunar radiation transmitted by glass to radiation absorbed by glass = 1/6. The glass used in my measures absorbed 23 per cent. of solar radiation, and transmitted 2 per cent. of radiation from a low temperature source, such as a boiling Leslie's cube. We must therefore increase the transmitted part by 21 per cent. to restore the proportion of reflected rays, and this gives:

$$\text{percentage of reflected rays} = \frac{121}{7} = 17.3.$$

The transmission of extreme infra-red rays by the Earth's atmosphere being larger in winter than the mean value — let us say 0.48 instead of the mean value 0.40 — and the mean transmission of the total moonbeam being one-half, while the atmospheric transmission of solar rays is 0.67, we get for the ratio outside our atmosphere:

$$\frac{17.3 \times \frac{3}{2}}{82.7 \times \frac{10}{4.8}} = \frac{1}{6.62},$$

and for the percentage reflected $\frac{100}{7.62} = 13.1$. This falls a little below the percentage for luminous rays. An albedo may be deduced from Zöllner's measures by dividing the theoretical ratio of the lunar disk to the hemisphere, supposed to reflect with albedo of unity to a central point, by the observed ratio of sunlight to moonlight, giving

$$\frac{97300}{618000} = 0.157.$$

Zöllner himself, assuming that the marked increase of light at the full is due to the roughness of the Moon's surface, applied a correction for light specularly reflected from crystalline facets,

and from elevations of every sort at an average angle of 52° with the surface of the sphere, getting 0.174 for the Moon's albedo.

The reflecting powers of various rocks for light run about like this:

White quartzite,	0.25
Clay shale,	0.16
Diorite, or dark slate,	0.09

Dark areas on the Moon may average a luminous albedo of 0.09. The surface of the Moon is about equally divided between dark and bright areas, and a mean albedo of 0.23 would be indicated for the bright parts, if 0.16 were adopted for the whole.

We need not assume that total reflected and luminous reflected rays are in identical proportions, although the difference is not very great; and as it has been found that long waves are less perfectly reflected by the Moon than short waves, there need be no hesitation in accepting for the combined lunar reflection of all sorts of solar rays, at least from regions within 60° of the subsolar point, a fraction as small as ⅛. It will be shown presently that marginal zones do not reflect uniformly in all directions, and that a larger fraction than ⅛ is required for them.

In illustration of the conditions of measurement, suppose that the bolometer at 300° Absol. is radiating to space at absolute zero, through the atmosphere. Its outgoing radiation of 0.010 radim is cut down to 0.005 radim by absorption, which is, in effect, as though the body of air had a like radiating power, and a temperature of 235°. Let a region of the Moon possessing a virtual temperature of 360° Absol., which corresponds to a radiating power to absolute zero (due in this case to combined reflection and emission) of 0.018 radim, be confronted with the bolometer. The lunar radiation reduced to 0.009 radim by absorption, combined with the effective radiation of the air, 0.005, is opposed to the potential 0.010 of the bolometer, and the balance stands thus:

Sky	Moon
± 0.000	+ 0.018 × ½ = + 0.009
+ 0.005	+ 0.005
− 0.010	− 0.010
− 0.005	+ 0.004

Radiation of Moon compared with sky :

$$+ 0.004 - (- 0.005) = + 0.009.$$

This observed radiation, multiplied by 2, and less ⅛, gives the proper radiation of the Moon :

$$\frac{0.009 \times 2 \times 7}{8} = 0.01575 \text{ radim},$$

corresponding to a genuine effective temperature of 346° Absol

It will be seen that temperatures deduced by this method rest on the value adopted for reflection of the combined bundle of rays from the Sun at the Moon's surface. This depends further upon the agreement of results, derived from the selective absorption of glass, with others depending on a comparison of the energy-curves of the solar and lunar spectra, together with estimates of atmospheric absorption in different regions of the spectrum, derived by various and somewhat complex methods, which also, however, now exhibit a fair degree of accordance. In applying the method to different lunar regions, it must be remembered that the fraction ⅛, given here for lunar reflection, is a mean value for central regions. Its variation must also be considered.

The percentage of reflected rays, as measured by the bolometer over somewhat wide areas after absorption by the atmosphere, has been found :

(*a*) smaller in dark regions than in bright : dark reflections = 50 to 70 per cent of bright ;

(*b*) smaller in dry cold weather than in moist and hot ; thus, in general, smaller in winter than in summer:

Apparent reflection (extreme dry) = 50 per cent. of extreme wet,
Apparent reflection (mean winter) = 70 per cent. of mean summer ;

(*c*) about 20 per cent. smaller in normal diffusively reflected and emitted radiation from low Sun areas than would be inferred, on the assumption of uniform reflection and absorption, from measures of the combined normal radiation in regions where the Sun is high;

(*d*) especially large — perhaps two to three times the usual proportion — in a narrow crescent Moon, where the rays suffer a grazing reflection at a large angle of incidence, the emission under a corresponding angle of emission being small.

Local variations of temperature on the Moon occur and are connected with the reflecting power. Thus bright regions reflect much, absorb little, and must be colder than dark regions, when the combined reflected and absorbed radiations for regions of similar insolation are identical. In general, such identity cannot hold after absorption by our atmosphere, the emanations from the dark parts being richer in absorbable rays, and thus appearing colder.

Regions near the subsolar point in *Oceanus Procellarum*, on January 17, 1889, gave deflections of 87 to 91 ^{div}. At the same time the bright highlands on the central meridian in 0° to 30° S. latitude, and far from the theoretical heat-center, gave 95 to 98 ^{div}. The coefficient for passing from dark to bright regions is therefore at least

$$96.5 \div 89.0 = 1.084.$$

From many comparisons under similar conditions of incidence, it appears that the total radiation of bright regions is 11 per cent. greater than the combined reflection and emission of dark regions. However, at a large angle of incidence, there is strong reflection at the same large angle of reflection, but diminished diffusive reflection at angles near the normal to the surface, as in reflection from the zone just within the terminator at first and third quarters; but dark areas do not reflect to the same extent, and normally they absorb and radiate more than bright in this position. (See "Prize Essay on the Distribution of the Moon's Heat," p. 37.) This is one reason, and possibly the principal one, why the phase curve for moonlight falls below

that for total radiation at the first and third quarters.[1] With a phase-angle of 70° from full Moon, I found a total heating effect 27.4 per cent. of that at the full, a day and a half after first quarter; and 37.5 per cent., a day and a half before third quarter, while Zöllner obtained 14.4 per cent. for the corresponding ratio of light. Evidently, the transmission by glass ought to be smaller at first and third quarters than at the full, and this is found to be the case. In fact, the relative radiating power of dark and bright regions near the terminator is reversed at these epochs, as just noted. I find also that measures of transmission by glass for the total moonbeam may frequently be arranged in a series according to their distance from full Moon, the transmission and inferred reflection being greater at the full, but I do not wish to insist too strongly upon evidence of this sort, because variations of atmospheric moisture produce equally great fluctuations. The following summer values with somewhat similar atmospheric conditions, are selected from the Allegheny measures:[2]

Transmission by glass:

23.3	per cent.	day of full Moon.
21.5	"	one day from full Moon.
18.6	"	three days from full Moon.
19.0	"	three days from full Moon.
15.2	"	seven days from full Moon.

A lampblack surface radiates nearly equably in all directions, but other substances have diminishing radiant and absorbent powers, and increased reflection, as the angle of the rays with a normal to the surface grows larger. Thus glass, which gives off 93 per cent. of the amount of radiation emitted by lampblack, provided the inclination of the emitted rays is nearly normal, radiates:

[1] The considerable area occupied by shadows at these phases partly accounts for the diminution of light. The shadows may radiate somewhat freely, being warmed from surrounding regions in sunshine.

[2] "The Temperature of the Moon," by S. P. Langley, assisted by F. W. Very. *Mem. Nat. Acad. of Sci.* **4**, 143, 145, 146, 147, 160.

86.4 per cent. at 60° from normal.
77.5 " at 70° from normal.
57.3 " at 80° from normal.

There is little change up to an angle of 60°, but beyond this the diminution of radiation is rapid. I found a similar diminution in the radiation from the subsolar point on the Moon as it departed from the center of the disk, but the relative dimensions of bolometer and lunar image did not permit the following of the effect to those large angles of emission in the narrow foreshortened margin near the limb, where it might be expected to be greatest; and the observations, being necessarily made on different dates, are not entirely comparable. With approximate correction for atmospheric condition, and reduction to standard brightness, these measures of subsolar radiation are as follows:

Angle of subsolar point from center of lunar disk		Observed radiation	Corrected radiation
4°	(bright region)	115 div	115 div
11	(dark region)	96	107
23	(bright region)	118	118
46	(dark region)	86	95
53	{ 34° from subsolar point reduced by mean curve }	79	92
61	(dark, air hazy)	61	85

The observations are neither numerous enough nor good enough to serve for deducing a mean curve of radiation according to the angle of the subsolar point from the center; but in obtaining a mean curve of lunar radiation as it varies with the inclination (i) of the solar rays to a normal at the lunar surface, I have profited by the knowledge of these probable changes, and have tried to avoid error by employing only central or nearly central positions.

From such measures, given in Table IX, the curves of the variation of lunar radiation along the Moon's equator in the lunar morning and afternoon have been prepared. These individual central measures have been supplemented, in drawing the final curves, by ratios derived from the mean phase curve

TABLE IX.

Date, 1889	t	Position	Period of lunar day	Zenithal defl'ction	Differential radiation	True emission	t	Sky deflection	Differential radiation of sky	Temp. of screen	Effective temperature of sky
				Div.	Radim	Radim		Div.	Radim		
January 23	102°	15° from central	Night	0.0	0.00000	0.00000	0°	—25.7	0.00491	281°	197° = — 76°C.
February 7	76	Central	A.M.	18.9	0.00361	0.00632	258	—20.2	0.00386	274	206 = — 67 C.
January 23	75	Central	P.M.	21.7	0.00414	0.00725	272	—25.7	0.00491	281	197 = — 76 C.
January 23	67	20° from central	P.M	43.7	0.00835	0.01461	337	—25.7	0.00491	281	197 = — 76 C.
April 10	61	Central	A.M.	40.1	0.00766	0.01341	329	—20.2	0.00386	289	238 = — 35 C.
January 12	46	Central	A.M.	59.7	0.01140	0.01995	372	—21.6	0.00413	281	214 = — 59 C.
January 17	38	27° from central	P.M.	85.9	0.01641	0.02872	417	—23.3	0.00445	285	216 = — 57 C.
April 15	31	27° from central	P.M.	102.0	0.01948	0.03409	438	—25.1	0.00479	287	213 = — 60 C.
April 13	23	Central	A.M.	106.6	0.02036	0.03563	448	—33.3	0.00636	285	164 = —109 C.
April 15	16	20° from central	A.M.	112.3	0.02145	0.03754	451	—25.1	0.00479	287	213 = — 60 C.
April 15	4	Central	P.M.	114.9	0.02195	0.03841	453	—25.1	0.00479	287	213 = — 60 C.

given in my essay, which represents the summation of many measures distributed over the lunar surface, eliminating local peculiarities. Thus the principal part of the radiation at first and third quarters comes from the zone 40° to 60° from the subsolar point. The mean radiation at third quarter is to that at first as $1\frac{1}{3}$ is to 1, giving the following average equatorial afternoon values by derivation from morning measures:

i	A.M.	P.M.
60°	1.33 × 41	= 54.5
50°	1.33 × 56	= 74.5
40°	1.33 × 74	= 98.4

The column headed t in the following table gives the concluded effective lunar temperature on the absolute Centigrade scale at the angle i from the subsolar point.

It is hardly possible at present to give a closer approach to a categorical statement of the lunar surface temperature than is contained in Table IX and the accompanying curves. If interior conduction is more rapid than has been here virtually assumed, midday surface temperatures may be lower, but retention of heat must then be greater.

I cannot emphasize too strongly the significance of the observations which prove that a few hours' deprivation of sunshine, as in a lunar eclipse, reduces the proper lunar radiation from its normal value at full Moon to less than 1 per cent., while in less than a day after the Sun has set, the night surface of the Moon gives no radiation sensible to our instruments. The Earth's atmosphere transmits probably at least 50 per cent. of extreme infra-red radiation such as must come from a body at very low temperature, and the measuring apparatus, according to the radiation curve, ought to be able to distinguish between radiators 25° apart, even near absolute zero. Hence, unless the Moon has an atmosphere capable of retaining these long ether-waves, the night temperature of the Moon can hardly exceed 50°, or at most 100°, on the absolute Centigrade scale. But the rapidity with which the Moon's surface cools in the afternoon shows that there is no such strongly absorbent atmosphere, and

the extremely low temperature of the lunar night is as nearly demonstrated as anything incapable of direct observation can be.

In the light of the preceding observation, one other mode of computing the lunar temperature may be used as a check. The Sun sends both Earth and Moon a radiation of 0.0500 radim, of which the Moon retains about 7/8 or 0.0438 radim, radiating its heat again from a surface virtually but little greater than twice the receiving section. Hence the mean proper radiation of the day side of the Moon is not much below 0.0219, corresponding to a mean temperature of 383° Absol. for blackened copper.

The Earth, by reason of its atmosphere, keeps its acquired temperature, and radiates both by night and by day through a surface four times the area of the absorbing section. If its reflecting power were the same as that of the Moon, its proper radiation would be 0.011 radim, corresponding to a mean temperature of 310° Absol. = + 37° C. in blackened copper. The actual mean temperature of the Earth is about 15° C., and the reflective power must therefore exceed that of the Moon, which is known to be the case from other considerations. If the Earth reflects 0.3 of the Sun's rays, the theory agrees with the facts; and it seems to me that this warrants the hypothesis that blackened copper is a fairly typical radiator for comparison with the Earth, the temperatures and emissions just given having been read from the curve of absolute radiation for this substance. But blackened copper may not be as good a choice for comparison with the Moon, where surfaces of dry rock take the place of water and vegetation, both of which agree well with lampblack as radiators. The surface temperature imparted by absorbed radiation, depends upon the capacity of the absorbing substance for heat, on the rapidity with which it conducts heat, and the consequent depth to which heat penetrates, and the mass of substance through which it is distributed, as well as upon the rate of reception and emission of radiation. If the irradiated body be very cold, its subsurface temperature-gradient may be so steep that the rate at which heat is conducted from the surface to the interior, forms a considerable fraction of the rate at which heat is supplied by

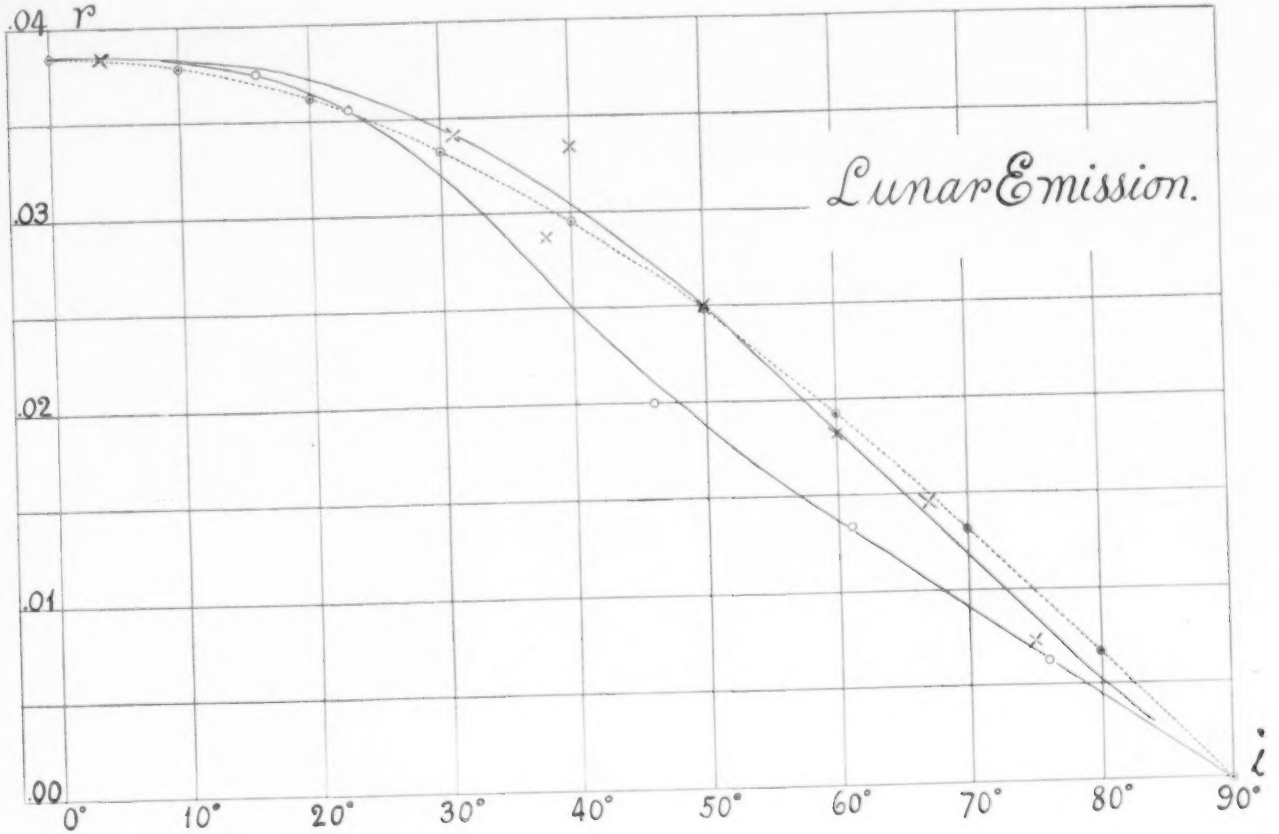
the radiant energy annihilated. In this case the surface temperature will be lower than that which the same radiation is capable of maintaining after the subsurface gradient is filled up; but if, after the heat capacity of the body has been satisfied, the received radiation falls off in intensity, a reversed flow of heat from the interior may preserve the surface temperature above the point which unaided radiation is capable of producing with the actual emissivity. In this way the solid substance of a nearly airless planet may exercise a retaining power for heat, and distribute temperatures over a wider interval, moderating excesses. The immobility of a solid prevents this mechanism from being anything like as effective as that of the Earth's atmosphere, which preserves the arctic regions from the cold of space during many months of darkness; but it is sufficient to give a very notable difference in temperature between the lunar morning and afternoon, and to make the diurnal temperature curve a little flat-topped.

TABLE X.

i	Radiation a. m.	$r_0 \cos i$	Radiation p. m.	Temperature	
				a. m.	p. m.
	radim	radim	radim		
0°	0.0385	0.0385	0.0385	454°	454°
10	0.0382	0.0379	0.0383	453	453
20	0.0365	0.0362	0.0372	447	450
30	0.0320	0.0333	0.0345	430	440
40	0.0250	0.0295	0.0304	400	424
50	0.0188	0.0248	0.0250	365	400
60	0.0137	0.0193	0.0188	331	365
70	0.0091	0.0132	0.0120	292	318
80	0.0045	0.0067	0.0052	227	240
90	0.0000	0.0000	0.0005	0	75

In Table X and the accompanying plate, r_0 being the maximum lunar radiation under a vertical Sun, i the angle of incidence of solar rays and also the angular distance of any region on the Moon, from the subsolar point, the ordinates of the curve, $r_0 \cos i$, are proportional to the insolation. Dots in circles indi-

PLATE IX.



cate this curve. Circles show the morning curve of emission, abscissae being angles from the subsolar point, and the afternoon observations of emission are denoted by crosses.

Table X gives only average values for every 10° of the subsolar angle.

The morning curve falls much below the curve of insolation, reaching its greatest actual, though not its greatest percentage departure, between the third and fourth day after lunar sunrise. Evidently heat is being stored up. But in the early part of the lunar afternoon, and for nearly three days after lunar midday, the curve of emission slightly exceeds that of insolation, following it closely, however, in the latter part of the afternoon, when cooling is very rapid, temperatures below the freezing point being reached twenty-four hours before sundown.

There may be local differences of heat-retaining power. Finger-like extensions of the isotherms beyond the lines of symmetry have been noted. But, on the whole, the peculiarities are not numerous, and no such extraordinary divergences from isothermal symmetry as our Earth exhibits, can find place on the Moon.

One other evidence of heat-retention may be mentioned. Measures of lunar radiation made all around the limb at full Moon show a slight preponderance at the poles. The incidence of the solar rays being the same in every case, and the nature of the surface not essentially different, we must infer that the poles are hotter because the Sun has been shining longer upon them.

The mean emission of the daylight hemisphere of the Moon has been estimated by the aid of the solar constant (p. 283) as something less than 0.0219 radim, admitting a reflection of one eighth of the solar rays at the Moon's surface; but the zone, 60° to 90° from the subsolar point, reflects more than this, hence the estimate must be reduced. We are now in a position where we can give a value from the lunar measures. Taking the products of the mean radiations by the areas of the zones in Table X, we have:

Zone	0° — 10°	0.00584
	10 — 20	0.01696
	20 — 30	0.02587
	30 — 40	0.03050
	40 — 50	0.03055
	50 — 60	0.02727
	60 — 70	0.02117
	70 — 80	0.01297
	80 — 90	0.00451
	Mean emission =	0.01952 radim

If the hemisphere were uniformly heated, this mean radiation would correspond to a mean temperature of + 97° C.

In conclusion, it seems to me reasonably certain that a large part of the Moon experiences daily great vicissitudes of temperature. Its rocky surface at midday, in latitudes where the Sun is high, is probably hotter than boiling water; and only the most terrible of Earth's deserts, where the burning sands blister the skin, and men, beasts, and birds drop dead, can approach a noontide on the cloudless surface of our satellite. Only the extreme polar latitudes of the Moon can have an endurable temperature by day, to say nothing of the night, when we should have to become troglodytes to preserve ourselves from such intense cold. Yet great as is the midday heat on the Moon, it might be even greater, if an atmosphere existed at all comparable with ours in density; and possibly the comparative absence of atmosphere which has been regarded by some as an insuperable barrier to life, may be the one condition needed for the preservation of some sort of life from destruction by the burning heat.

PROVIDENCE, R. I.,
August 1898.

PHOTOGRAPHS OF COMET I, 1898 (BROOKS), MADE WITH THE CROSSLEY REFLECTOR OF THE LICK OBSERVATORY.

By James E. Keeler.

Although the three-foot reflector presented to the Lick Observatory by Mr. Crossley was set up in its present place some time ago, it has been little used, chiefly for lack of the necessary assistance in managing it. I have recently, through the appointment of several Fellows from the astronomical department of the University, at Berkeley, been able to bring this instrument into active service, and have employed it for a number of different purposes. I shall reserve an account of its performance and capabilities for a future paper, and shall limit the present note to a description of some photographic observations of the comet discovered by Mr. Brooks on October 20.

For photographing stars and nebulæ the reflector is provided with a double slide plate-holder and guiding eyepiece of the form devised by Dr. Common. The precision with which stars can be followed with this apparatus leaves nothing to be desired. But for guiding the instrument in photographing a comet there is at present no better arrangement than a four-inch finder, of eight and one-half feet focal length, attached to one of the four iron standards which form the "tube" of the telescope. It will readily be understood that the results of guiding a three-foot telescope with a four-inch finder are not entirely satisfactory. In photographing a comet the trails left by the stars in their relative motion consist of a great number of irregular zigzag lines, the departures of which from the mean position, or axis of the trail, roughly measure the disparity in the optical powers of the two telescopes.

With the assistance of Mr. H. K. Palmer, Fellow in Astronomy at the Lick Observatory, I obtained photographs of Brooks' comet on eleven consecutive nights, from November 4 to Novem-

ber 14, inclusive. At first it was possible to give an exposure somewhat exceeding one hour in length; but the comet was moving rapidly southward, and the limits set by the end of twilight on the one hand, and the construction of the mounting of the telescope on the other, soon narrowed, so that by November 14 the greatest possible exposure was reduced to thirteen minutes. The observations were then discontinued.

The best photograph was obtained on November 5 with an exposure of $1^h\ 10^m$. On this plate the extreme diameter of the coma is 0.25 inch$=4'.1$. A very narrow straight tail extends from the center of the head to a distance of 1.4 inch, or $23'$. In appearance the comet closely resembles Comet b, 1894 (Gale), as photographed by Barnard.[1]

A photograph made by Mr. Palmer on the night of November 3, with the Willard six-inch portrait lens, closely resembles this photograph, though the scale is of course very much smaller. The exposure was $1^h\ 17^m$. The tail as shown on the plate is about $45'$ long.

At the end of each exposure with the Crossley telescope the driving-clock was stopped, and the stars were allowed to trail on the plate for about two minutes, in order to obtain reference lines for the measurement of position angles. No perceptible trail was left by the comet.

The tail is shown best on the photograph of November 5. It is much shorter and less distinct on my other negatives, which received shorter exposures, and is barely visible on plates which were exposed for less than thirty minutes. The position angle of the tail was measured on six plates, with the following results, which may have some interest in connection with theories of the physical constitution of comets. In the table r is the computed position angle of the radius vector of the comet, and t is the position angle of the tail.

On November 6 several photographs were taken with exposures of different lengths, instead of giving all the available time to one long exposure. These plates showed a very small, almost

[1] *A. and A.* 13, 421, 1894.

stellar nucleus, which was easily photographed with an exposure of four minutes—the shortest that was tried.

Date	R. A.	Dec.	r	t	$r-t$
	h m s	° ′	° ′	° ′	° ′
1898, Nov. $5^d\ 7^h$	17 34 53	+17 12	53 55	48 37	+5 18
Nov. 7 7	17 41 56	14 21	54 49	52	+2 49
Nov. 8 7	17 45 7	12 32	55 40	52½	+3 10
Nov. 9 7	17 48 0	10 51	56 19	53	+3 19
Nov. 10 7	17 50 30	9 19	56 51	55	+1 51
Nov. 12 7	17 55 3	+ 6 21	57 53	60	−2 7

The uncertainty of guiding, to which I have referred, affects, of course, the impression of the comet on the plate, as well as the star trails. Certain irregularities in the outline of the head and in the shape of the nucleus, which appear on some of the plates, are in general attributable to this cause. There is reason to believe that other appearances of the kind are real. The effect of imperfect guiding on the image of the comet can be ascertained by a study of the star trails, in which all errors of pointing are accurately registered, and in one or two cases some other explanation of the observed irregularities seems to be required.

On the negative of November 10, obtained with an exposure of 50^m, the head of the comet is made up of two clearly separated nebulous masses, surrounded by the nearly circular coma. The centers of these masses are 1^{mm} apart, and the line joining them is nearly at right angles to the general direction of the star trails. The short zigzag lines which make up the latter are, however, practically all included within a strip $\frac{1}{3}^{mm}$ wide, and there is no evidence in the trails that the errors in the pointing of the telescope were grouped around two distinct and slightly different values. The guiding was neither better nor worse than usual.

The appearance described above is therefore not explicable as a result of imperfect guiding. I am inclined to believe that the division of the nucleus was real. It was not certainly visible with the twelve-inch and thirty-six-inch refractors; but it is well known that short exposure and forced development of a photo-

graph greatly exaggerates contrasts of light and shade, and in this case the differences in the brightness may have been so slight as to escape direct visual observation. The separation of the head of a comet into distinct masses is not an unusual phenomenon, and it is one which causes considerable embarrassment to the observer with the micrometer. In this case the separate masses were not marked strongly enough to be visible, and they were symmetrically situated with respect to the center of the coma, so that no appreciable effect on measures of position which may have been made at the time is to be apprehended.

On the photographs of November 11 there was no separation of the nucleus to be seen.

These preliminary results show that the Crossley reflector only needs a sufficiently powerful guiding telescope to become an efficient instrument for the photography of comets, and as soon as possible the necessary apparatus will be provided.

THE VARIABLE VELOCITY OF o LEONIS IN THE LINE OF SIGHT.

By W. W. CAMPBELL.

MY measures of four spectrum plates of *o* Leonis ($\alpha = 9^h\ 36^m$, $\delta = +\ 10^\circ\ 21'$) give the following velocities with reference to the solar system :

1898 — March 22, V = + 66^{km}.7 per second.
Oct. 31, V = − 30 ± " "
Nov. 1, V = − 23 ± " "
Nov. 4, V = + 40.0 " "

It will be seen that the velocity varies between wide limits, probably in a comparatively short period of time. The extreme range observed thus far is about 97^{km} per second.

All the photographs were obtained under extremely poor atmospheric conditions. The second and third photographs are unsuitable for accurate measurement, and they will not be used in future discussions of the motion.

There is some evidence that the spectrum consists of two superposed spectra.

LICK OBSERVATORY,
Nov. 5, 1898.

THE VARIABLE VELOCITY OF χ DRACONIS IN THE LINE OF SIGHT.

By W. W. CAMPBELL.

THE velocity of χ Draconis ($\alpha = 18^h\ 23^m$, $\delta = +72°\ 42'$) in the line of sight is variable, having a range of about 40^{km} per second. The first three photographs secured gave little indication of a variable velocity. The first evidences of variation were detected by Mr. Wright while developing the plate of October 25. The velocities determined to date are given below:

Mt. Hamilton M. T.	Velocity		Mt. Hamilton M. T.	Velocity	
1898, July 25,	$+45^{km}.6$		1898, November 1,	$+11^{km}.9$	
September 5,	+46 .0		November 5,	+11 .3	
September 19,	+42 .6		November 12,	+10 .7	
October 24,	+14	$\pm$[1]	November 18,	+10 .6	
October 25,	+16	$\pm$[1]	December 3,	+15	$\pm$[1]
October 26,	+14 .5		December 7,	+18 .3	

The observations seem to indicate a period of between five and six months. At the present time the velocity is rapidly increasing. The spectrum does not appear to be composite.

The period of *o* Leonis, recently announced, is very close to 14½ days. The range is about 112^{km}.

The period of η Pegasi seems to be about 2¼ years.

LICK OBSERVATORY,
December 9, 1898.

[1] The plates of October 24, October 25, and December 3 are poor, and the approximate results assigned to them were obtained from hasty and incomplete measures of a few lines. While they fall very close to the velocity curve furnished by the other observations, it is not intended to use them in subsequent discussions.

ON THE CONSTITUTION OF GASEOUS CELESTIAL BODIES.

By A. RITTER.

EDITORIAL INTRODUCTION.

BETWEEN the years 1878 and 1883 a series of eighteen papers by A. Ritter, of Aachen, appeared in *Wiedemann's Annalen* under the title, "Researches on the height of the atmosphere and the constitution of gaseous celestial bodies." These seem to have received hardly the attention they deserve, and at the suggestion of one of our associates we have translated one of the most important papers of the series. This is the sixteenth paper, from Bd. XX of the *Annalen*, and it is of especial interest from its bearing on the question of stellar classification. It will be seen that the author, reasoning on purely physical grounds and assumptions, arrives at a classification which includes stars with rising temperature as well as those with falling temperature. Thus he infers that the red stars of class III a have not reached the acme of their brilliance, and that those of class III b (Secchi's fourth type) are nearing extinction after having run their course of stellar evolution.

Many assumptions and hypotheses are made in the series of papers that have not been substantiated or have been disproved by more recent researches, but the author frankly and clearly states what are assumptions and what are facts of observation.

The fundamental assumption is the principle of the neutral equilibrium of a gaseous atmosphere. This is stated as follows: "When a vertical motion is given to a small mass of air at any point in the atmosphere otherwise at rest, it expands as it rises, and its temperature consequently falls. The slow rise of the small mass of air will be *uniform* motion if the impelling force at every point exactly balances gravity. This condition will be

fulfilled if the temperature of the rising air is always the same as that of the air into the neighborhood of which it comes.

"As no transfer of heat occurs at equal temperatures, the condition of adiabatic expansion of the rising air will in this case be also fulfilled. A uniform upward motion and adiabatic expansion then require the common condition that the vertical temperature gradient of the air at rest shall coincide with the adiabatic gradient of the rising air. This condition being satisfied, the atmosphere will be in neutral equilibrium.

"This may be regarded in a sense as the normal state of the atmosphere, for temporary instability always develops motions (storms, etc.), which lead to neutral equilibrium, and the relatively high temperature of the Earth's surface prevents a long continuance of stable equilibrium. In general the neutral state is to be regarded as the final condition which will always result from any initial condition whatever, provided the different strata of air fully and freely mingle with each other." (*Wied. Ann.* **5**, 405–406.)

The term "condition-line" (*Zustandslinie*) frequently employed by the author is defined as follows: "At the separate points of a straight line drawn from the center to the surface of a gaseous celestial body, its matter is in different conditions; and we may assume that the condition varies continuously along that line if the body is composed of an elemental substance having the properties of a perfect or ideal gas. Since a definite point of the temperature surface corresponds to each definite condition of the gas, the law of the space-rate of change of condition may be geometrically represented by a continuous line. This we shall call the condition-line of the body. On the hypothesis of neutral equilibrium the condition-line of a celestial object in an entirely gaseous state is an adiabatic curve." (Bd. **5**, 547.)

We have retained the numbering of paragraphs and equations given in the original article, for the convenience of reference to earlier papers of the series. To assist further in this respect the following list of Ritter's papers is appended:

REFERENCES TO RITTER'S ARTICLES IN "WIEDEMANN'S ANNALEN."

Numbers	Sections	Equations	Volume	Pages
I	1– 7	1– 41	5	405–425
II	8–11	42– 80	5	543–558
III	12–14	81–133	6	135–144
IV	15–17	134–175	7	304–317
V–VI	18–26	176–245	8	157–183
VII	27–29	246–281	10	130–143
VIII	30–33	282–324	11	332–344
IX	34–36	325–358	11	978–997
X	37–40	359–393	12	445–465
XI	41–44	394–449	13	360–377
XII	45–48	450–498	14	610–634
XIII	49–55	499–584	16	166–192
XIV	56–60	585–593	17	322–342
XV	61–63	594–596	18	488–508
XVI	64–68	597–637	20	137–160
XVII–XVIII	69–76	638–659	20	897–927

§ 64. HEAT RADIATION OF AN ADIABATIC SPHERE OF GAS.

The adiabatic condition-line of an ideal gaseous sphere represents an increase of temperature with increasing depth below the surface, and in the immediate proximity of the surface the temperature increment dT corresponding to the depth increment dz can be calculated from the formula

$$\frac{dT}{dz} = \frac{T_0}{ar}, \tag{597}$$

where r denotes the radius of the sphere, T_0 the temperature of its center, and a a constant depending on the value of the ratio of specific heats at constant pressure and constant volume, $k = \frac{c_p}{c_v}$. The latter can be represented geometrically by the surface F bounded by the gravitation curve (§ 31, Fig. 7). For $k = 1.41$ (§12 and §31), a becomes 2.4, and in general a can be computed from the approximate empirical formula

$$a = 0.5 + \frac{0.4}{k - 1.2} \tag{598}$$

For small values of the ratio $\frac{z}{r}$ the temperature at the depth z below the surface can be computed from the formula

$$\frac{T}{T_0} = \frac{z}{ar}, \tag{599}$$

and since under an adiabatic condition the temperatures vary as the $(k-1)$-th powers of the densities (Eq. 309), we obtain for the ratio of the corresponding densities

$$\frac{\gamma}{\gamma_0} = \left(\frac{z}{ar}\right)^{\left(\frac{1}{k-1}\right)}. \tag{600}$$

The mass of the surface layer of thickness z, per unit of surface, is

$$\mu = \int_0^z \gamma \, dz, \tag{601}$$

and if we substitute the value for γ obtained above and perform the integration, we shall obtain for this surface layer

$$\mu = \left(\frac{k-1}{k}\right) \gamma_0 (ar)^{-\left(\frac{1}{k-1}\right)} z^{\left(\frac{k}{k-1}\right)}. \tag{602}$$

The above equations hold not only for the given conditions, but also for any other adiabatic condition of equilibrium whatever, into which we can imagine the gaseous sphere to be brought, and for a given value of μ we shall obtain for the thickness of a surface layer of this mass a smaller value, the greater the density of the sphere is assumed to be. If the radius were to decrease to the value $\frac{r}{n}$, the density of the center would become $n^3 \gamma_0$, and the temperature of the center $n_0 T$ (from § 8). Under this new adiabatic condition of equilibrium, the depth of the surface layer at which the mass-intensity would again assume the value μ would be calculated from the equation

$$\mu = \left(\frac{k-1}{k}\right) n^3 \gamma_0 \left(\frac{ar}{n}\right)^{-\left(\frac{1}{k-1}\right)} z_1^{\left(\frac{k}{k-1}\right)}. \tag{603}$$

On equating the two expressions now found for μ we obtain as the ratio of z and z_1

$$\frac{z}{z_1} = n^{\left(\frac{2-3k}{k}\right)}. \tag{604}$$

The temperature T_1 corresponding to the value z_1, can be computed from equation (599) by applying it to the new condition of equilibrium, whence

$$\frac{T_1}{n\,T_0} = \frac{z_1}{a\left(\frac{r}{n}\right)}. \tag{605}$$

Therefore

$$\frac{T_1}{T} = n^2 \frac{z_1}{z}, \tag{606}$$

and after substituting the value of $\frac{z_1}{z}$ from the expression above we obtain

$$\frac{T_1}{T} = n^{\left(\frac{2-k}{k}\right)}. \tag{607}$$

Since the law of the increase of temperature and density with increasing depth below the surface remained unchanged during the transition to the new condition of equilibrium, the ratio of the maximum temperatures T_1 and T here found indicates at once in what ratio the mean temperature of the surface layer of mass μ has increased during the change of the sphere to the denser and hotter condition.

Under the assumption of a sufficient density of the gaseous sphere, we may assume that the thickness of the surface layer whose particles send out heat radiations directly into empty space, constitutes a comparatively small fraction of the whole radius of the sphere. If we further make the provisional assumption (reserving a correction to be later applied) that the mass-intensity of this radiating layer is independent of its mean temperature, and possesses one and the same value μ for all conditions of the sphere, then the above quantity can at the same time be considered as the ratio in which the mean temperature of the radiating surface layer has increased during contraction,

or more briefly, as the ratio in which the surface temperature of the gaseous sphere has increased.

According to Stefan's researches the intensity of heat radiation varies approximately as the fourth power of the absolute temperature of the surface. Accordingly we get for the ratio of the heat radiation per unit of surface

$$\frac{q_1}{q} = \frac{T_1^4}{T^4} = n^{\left(\frac{8-4k}{k}\right)}. \tag{608}$$

Since the surfaces vary as the squares of the radii, the ratio of total quantities of heat radiated per unit of time is

$$\frac{Q_1}{Q} = \frac{1}{n^2}\frac{q_1}{q} = n^{\left(\frac{8-6k}{k}\right)}. \tag{609}$$

This equation shows that $Q_1 = Q$ when $k = \frac{4}{3}$, and that Q_1 is less than Q when k is greater than $\frac{4}{3}$. Since the adiabatic condition of equilibrium of a gaseous sphere can only be maintained permanently when k is greater than $\frac{4}{3}$, as was shown in § 33, the last case only comes under consideration. For an ideal hydrogen sphere k would be 1.41, and for this case the following numerical values obtain:

$n = 1$	2	10	100
$\frac{T_1}{T} = 1$	1.336	2.621	6.868
$\frac{q_1}{q} = 1$	3.2	47	2226
$\frac{Q_1}{Q} = 1$	0.8	0.47	0.22

If we should place $k = \frac{5}{3}$ we should get:

$n = 1$	2	10	100
$\frac{T_1}{T} = 1$	1.15	1.585	2.512
$\frac{q_1}{q} = 1$	1.74	6.3	39.8
$\frac{Q_1}{Q} = 1$	0.436	0.063	0.00398

These numerical values are based upon the inaccurate assumption that the mass intensity of the radiating surface layer remained unchanged during the transition of the sphere to the hotter and denser condition. Since the absorptive power of a stratum of gas in all probability increases with rising temperature, smaller values than the above should be used for the mass-intensity, and hence for the mean temperature, in order to make allowance for this fact. In actuality, therefore, the quantity of heat radiated per unit of time will decrease with gradual condensing of the sphere more rapidly than found above.

Since we may assume that the quantity of light emitted will diminish simultaneously with the quantity of heat radiated, it follows that a decrease in the luminosity of a star may accompany an increase of the interior heat. A falling off in light, therefore, by no means premises a previous decline of temperature as a necessary condition. A decrease in the light of a star may indeed occur while the interior heat and the surface temperature are still increasing.

The Sun is at present in a condition to elude an answer to the inquiry whether its mean temperature is still increasing or already decreasing. In any case, however, the Sun has already attained a condition of density such that the fulfillment of the above assumption of a comparatively slight depth of the radiating surface layer is hardly to be doubted. From the results of the above investigation we may therefore reason with a high degree of probability that under any circumstances — whether the Sun's temperature be increasing or decreasing — the total yearly heat radiation from the Sun is at present already on the decline, therefore that the Sun is to be considered as a star gradually beginning to disappear, or as a star that has already entered the stage of diminishing light intensity.

[The investigation of § 11 necessarily led to the opposite result, because the assumption was there made that with the rise of the interior heat of a gaseous celestial body, the temperature of radiation — or the mean temperature of the particles whose radiations are sent directly out into space — increases in the same

proportion as the mean temperature of the whole body. The investigation just made shows that this assumption and the conclusions based upon it must be regarded as inapplicable to the case of the Sun in its present condition of density.]

§ 65. HYPOTHESES AS TO THE LAW OF CONTRACTION OF THE SUN.

The potential of an ideal gas ball of mass S in a condition of adiabatic equilibrium can be computed (§ 32) from the equation

$$\mathfrak{u} = \left(\frac{3k-3}{5k-6}\right) N r S, \tag{610}$$

in which N denotes the force of gravitation per unit of mass at the surface layer. The mechanical equivalent of its interior heat has (§ 20) the value

$$U = \frac{\mathfrak{u}}{3k-3}. \tag{611}$$

The potential $\mathfrak{u}$ can be regarded as the mechanical work the forces of gravitation would perform if the radius decreased from ∞ to r. We may regard this work as resolved into the two components U and $\mathfrak{u}-U$, of which the first is used for producing the interior heat, and the second for developing the heat radiated outward during contraction. This latter quantity of heat has therefore the value

$$W = A(\mathfrak{u} - U) = A\left(\frac{3k-4}{3k-3}\right)\mathfrak{u} \qquad \text{or} \tag{612}$$

$$W = \left(\frac{3k-4}{5k-6}\right) A N r S. \tag{613}$$

If $N = N_0$ when $r = r_0$, we have from the law of gravitation

$$N r^2 = N_0 r_0^2, \tag{614}$$

and after substituting this value for N, the above equation takes the form

$$W = \left(\frac{3k-4}{5k-6}\right) \frac{A N_0 r_0^2 S}{r}. \tag{615}$$

By differentiating with respect to the time t, we obtain for

the quantity of heat sent outward from the whole sphere in each unit of time

$$\frac{dW}{dt} = -\left(\frac{3k-4}{5k-6}\right)\frac{A N_0 r_0^2 S}{r^2} \cdot \frac{dr}{dt}. \qquad (616)$$

The average quantity of heat given out by each kilogram of mass is therefore

$$w = -\left(\frac{3k-4}{5k-6}\right)\frac{A N_0 r_0^2}{r^2} \cdot \frac{dr}{dt}. \qquad (617)$$

If σ denotes the amount by which the radius diminishes per unit of time, for instance per year, then we may place

$$\sigma = -\frac{dr}{dt} \qquad (618)$$

and from the above equation we get

$$(619) \quad \sigma = \left(\frac{5k-6}{3k-4}\right)\frac{w r^2}{A N_0 r_0^2} \quad , \quad \sigma_0 = \left(\frac{5k-6}{3k-4}\right)\frac{w_0}{A N_0}. \qquad (620)$$

In applying these equations to the Sun (where the quantities with subscript zero are taken to apply to its present condition) we accordingly make $N_0 = 27.4$, $w_0 = \frac{4}{3}$, and find for σ_0 and k the following corresponding values:

$k = 1.41$	$\frac{5}{3}$
$\sigma_0 = 94075^{m}.$	$48083^{m}.$

From equations above we obtain

$$\frac{\sigma}{\sigma_0} = \frac{w r^2}{w_0 r_0^2}. \qquad (621)$$

Since the quantities of heat given out per unit of mass vary as the total quantities radiated, we place (609)

$$\frac{w}{w_0} = \left(\frac{r}{r_0}\right)^{\left(\frac{6k-8}{k}\right)}, \qquad (622)$$

and if at the same time we substitute for σ its value given in equation (618), we shall get an equation which we can put in the form

$$dt = -\frac{dr}{\sigma_0}\left(\frac{r}{r_0}\right)^{\left(\frac{8-8k}{k}\right)}. \qquad (623)$$

The time in which the Sun's radius decreased from r to r_0 can therefore be computed from the equation

$$t = -\frac{r_0^{\left(\frac{8k-8}{k}\right)}}{\sigma_0} \int_r^{r_0} r^{\left(\frac{8-8k}{k}\right)} dr, \qquad (624)$$

or

$$t = \frac{k\, r_0}{(7k-8)\,\sigma_0} \left\{ 1 - \left(\frac{r_0}{r}\right)^{\left(\frac{7k-8}{k}\right)} \right\}. \qquad (625)$$

If we now first put $k = 1.41$ and hence $\sigma_0 = 94075^{m}$., this equation assumes after substitution of $r_0 = 688\,000\,000^{m}$ the form

$$t = 5\,514\,312 \left\{ 1 - \left(\frac{r_0}{r}\right)^{1.326} \right\}. \qquad (626)$$

For corresponding values of $\frac{r_0}{r}$ and t, we thus get

$\frac{r_0}{r} =$	1	$\frac{1}{2}$	$\frac{1}{10}$	$\frac{1}{106}$	$\frac{1}{215}$
$t =$	0	3 315 060	5 254 154	5 502 036	5 509 864.

Since the radius of the Earth's orbit is about 215 times the present solar diameter, it follows — on the assumptions made here — that about 5.5 million years ago the solar radius was of the same size as the radius of the Earth's orbit.

The premise of the above conclusion was that the depth of the radiating surface layer was always small in comparison with the radius of the gas ball. It therefore now remains to inquire whether that condition can also be regarded as approximately satisfied under a 215-fold magnification of the Sun's radius.

If we take $\mu = 1\,000\,000^{kg}$, — which is equivalent to supposing that a gaseous layer whose mass-intensity amounts to more than a million kilograms per square meter is almost completely opaque to heat rays — we shall obtain the following results for $\frac{r_0}{r}$ and $\frac{z}{r}$, after substituting in equation (602) the values $\alpha = 2.4$, and $\gamma = 31416^{kg}$, corresponding as above to $k = 1.41$:

$$\frac{r_0}{r} = \quad 1 \qquad \frac{1}{2} \qquad \frac{1}{10} \qquad \frac{1}{100} \qquad \frac{1}{215}$$

$$\frac{z}{r} = 0.019625 \quad 0.029365 \quad 0.07488 \quad 0.28574 \quad 0.44588.$$

This table shows that the above condition cannot be regarded as sufficiently fulfilled for the larger values of r, especially for $r = 215 r_0$, so that the values of t found above require a correction on this account, making them larger than we have found; for those values presuppose that the radius of the radiating spherical shell, or the mean radius of the radiating surface-layer, was always nearly as large as the whole radius r, while in fact at the time when $r = 215 r_0$, that radius was considerably smaller.

Equation (626) and the table calculated from it show, however, that the value of t increases with r the more slowly as the radius r is greater; and since the above mentioned correction chiefly affects the values of t corresponding to the larger values of r, the absolute values of t will only be slightly altered (even if the differences of the values of t may suffer comparatively large changes), since the correction can never amount to more than a relatively small fraction of the whole absolute value.

According to the above table we shall find, on the assumption that the radius of the radiating spherical surface was always as large as the radius of the whole surface, that the solar radius decreased from the size $215 r_0$ to $10 r_0$ in 255 710 years. Should we make instead the assumption that the radiating surface was constantly half the whole surface (an assumption that would in any case give too great a value for the time, namely, 511 420 years, or twice as many as before) we should obtain for the whole interval in which the Sun's radius contracted from $215 r_0$ to its present size $t = 5\,765\,578$ years (instead of 5 509 864). Hence even in this case we should get a value only about 4.6 per cent. larger than that found originally. In this way we may easily convince ourselves that the original values of t are to be regarded as sufficiently close approximations, in spite of the imperfect fulfillment of our assumption.

If we should use $k = \frac{5}{3}$ instead of 1.41, to which would then

correspond $a=1.35$, $\sigma_0=48083^{m}$, $\gamma_0=8568^{kg}$, we should obtain from equation (625) the value

$$t=6\,504\,000\left\{1-\left(\frac{r_0}{r}\right)^{2.2}\right\}, \qquad (627)$$

and repeating our calculation with these data we should arrive at the following table:

$\frac{r_0}{r}=$	1	$\frac{1}{2}$	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{213}$
$t=$	0	5088730	6462955	6503741	6503952
$\frac{z}{r}=$	0.00338	0.005877	0.021339	0.134637	0.248384.

This last row of figures shows that also in this case the values of t calculated directly from (627) can be regarded without hesitation as close enough approximations. Since the mechanical theory of heat teaches that $k=\frac{5}{3}$ is the largest possible value of $\frac{c_p}{c_v}$, it follows from the table that the time during which the Sun's radius contracted from $215r_0$ to its present size could at most have amounted to about 6.5 million years.

We should arrive at still smaller values if we took account of the fact that recent observers[1] agree in finding the quantity of heat radiated yearly from the Sun at least 50 per cent. greater than the amount given by Pouillet, from which the value $w_0=\frac{4}{3}$ was assumed. If we shall therefore place $w_0=2$, we should get for the interval for either value

$$k=1.41 \text{ or } k=\tfrac{5}{3},$$
$$t=3\,673\,241, \text{ or } t=4\,335\,968 \text{ years.}$$

The above results were deduced from the supposition that the Sun had a spherical shape throughout the whole interval t, and that the whole mass constantly preserved a purely gaseous condition. For the last part of the time, for instance during the period of solar contraction from $2r_0$ to r_0, this supposition is perhaps sufficiently justified; but in the earlier times, especially

[1] LANGLEY, The Mount Whitney Expedition. *Nature*, 1882; *Wied. Ann.* 19, 384, 1883.

when the Sun's radius extended to the Earth's orbit, we must nevertheless consider that conditions differed considerably from those supposed here.

To obtain a more accurate value of t we should first have to take into consideration the fact that the motion of rotation of the Sun must in early times have caused a considerable departure from the spherical shape; and on the other hand that at that time the mass-intensity and the mean temperature of the radiating surface layer may possibly have been considerably modified by the occurrence of processes of condensation.

The possibility does not therefore appear *a priori* excluded that the introduction of that correction would produce a comparatively large change in the entire value of t, even if we may suppose that the correction (as in the case of the correction above applied to z) probably would be required for only a relatively small part of the whole interval—as for instance the time in which the solar radius decreased from $215 r_0$ to $2 r_0$ amounted by the last table to only about 22 per cent. of the whole value of t.

For these reasons we cannot give to the maximum value $t =$ 4 336 000 years found above the significance of a superior limit for the age of the Earth, the less in fact since the original assumptions must still be regarded as hypotheses imperfectly satisfied. Nevertheless it seems permissible to conclude from the above investigation that the actual age of the Earth must be far less than the estimates of some geologists, who place it at hundreds of millions of years.

§64. HYPOTHESES AS TO THE CONSTITUTION OF THE WHITE STARS.

After substituting in (599) the value of z from (602) we obtain for the maximum temperature of the radiating surface layer, or for the temperature of its inner bounding surface,

$$T = T_0 \left\{ \frac{\mu k}{\gamma_0 (k-1) a r} \right\}^{\frac{k-1}{k}} \qquad (628)$$

On applying this same equation to the case of another sphere of the same constitution, with the only approximately accurate assumption that the mass-intensity of the radiating surface is independent of its temperature, we find as the ratio of the two boundary temperatures

$$\frac{T}{T'} = \frac{T_0'}{T_0}\left(\frac{\gamma_0' r'}{\gamma_0 r}\right)^{\frac{k-1}{k}} \tag{629}$$

If S and S' are the masses of the two spheres, the ratio of the temperatures of their centers will be (by §12 and §31)

$$\frac{T_0}{T_0'} = \frac{S}{S'} \cdot \frac{r'}{r}, \tag{630}$$

and since the ratio of the boundary temperatures of the radiating surface layers coincides with the ratio of their mean temperatures, the latter will have the value

$$\frac{\tau}{\tau'} = \frac{S}{S'} \cdot \frac{r'}{r}\left(\frac{\gamma_0' r'}{\gamma_0 r}\right)^{\frac{k-1}{k}}, \tag{631}$$

which may be briefly called the ratio of the surface temperatures. If further δ and δ' denote the mean densities of the two spheres, we can place

(632) $$\frac{\gamma_0}{\gamma_0'} = \frac{\delta}{\delta'} \text{ and } \frac{S}{S'} = \left(\frac{r}{r'}\right)^3 \cdot \frac{\delta}{\delta'}. \tag{633}$$

Using these expressions (631) takes the form

$$\frac{\tau}{\tau'} = \left(\frac{S}{S'}\right)^{\frac{k+1}{3k}} \cdot \left(\frac{\delta}{\delta'}\right)^{\frac{2-k}{3k}}. \tag{634}$$

If we premise similar physical and chemical properties for the substances composing the Sun and stars, this equation can serve to answer the question—Under what circumstances can the surface temperature of a star exceed the present surface temperature of the Sun? where the expression surface temperature is always to be understood as above explained.

The numerical values for the two exponents of the above equation are:

$$\begin{array}{lll} k = \frac{4}{3} & 1.41 & \frac{5}{3} \\ \frac{(k+1)}{3k} = \frac{7}{12} & 0.57 & \frac{8}{15} \\ \frac{(2-k)}{3k} = \frac{1}{6} & 0.14 & \frac{1}{15}. \end{array}$$

This table shows that the exponent of the mass-ratio is almost independent of k and is always slightly more than 0.5. Since our assumption of independence of absorption from temperature would anyhow lead to too high values of these exponents, we can in an approximation place it equal to 0.5, whence the following proposition:

The surface temperatures of two stars of equal densities are to each other nearly as the square roots of their masses.

If S is placed equal to S', the ratio of the surface temperatures is

$$\frac{\tau}{\tau'} = \left(\frac{\delta}{\delta'}\right)^{\frac{2-k}{3k}} \qquad (635)$$

The values of the exponents of the density-ratio given in the table indicate that in the cases chiefly coming under consideration — with the larger values of k — the surface temperature can be considered as nearly independent of the density, since a significant rise of the surface temperature would only occur under a very great increase of density.

Thus for the ratio $\frac{\tau}{\tau'} = 2$, the ratios of increase of density would be

$$\begin{array}{lll} \text{for } k = \frac{4}{3} & 1.41 & \frac{5}{3} \\ \frac{\delta}{\delta'} = 64 & 144 & 32768. \end{array}$$

For the present central density of the Sun we should get (from § 31)

$$\begin{array}{lll} \text{for } k = \frac{4}{3} & 1.41 & \frac{5}{3} \\ \delta_0' = 81\,400 & 31\,416 & 8\,568 \end{array}$$

The comparison of these two tables shows that the assumption of a comparatively slight power to rise for the surface tempera-

ture would predicate a possibility of the increase of its central density beyond the range of probability, whatever the value taken for the ratio of the specific heats. It is therefore decidedly improbable that the surface temperature of the Sun will increase significantly in the future. We may perhaps with greater probability assume that it is already on a slow decline.

The above values for the present central density of the Sun were deduced on the supposition of an unlimited validity of Mariotte's law, and they can be called the "theoretical" in contrast to the "actual" central densities. It is highly probable that the actual is less than the theoretical central density, so that we infer that the Sun long ago passed the stage of development at which the approximate validity of Mariotte's law ceases in consequence of the gradual increase of the density. If, however, the actual central density is less than the theoretical, then the actual density of the surface layer must be greater than the theoretical, and hence the actual surface temperature must be less than the theoretical because the depth from which heat is directly radiated into empty space will be less as the density of the surface layer is greater.

Since the departure from Mariotte's law grows with increasing density, the difference between the actual and the theoretical surface temperature must have been less in earlier times than now (as on account of less density the departure was also less), and hence the possibility is not excluded that then the actual surface temperature was higher than now. In any case the possible differences between the present surface temperature and a maximum value perhaps reached then are comprised within narrow limits. At no period could the actual surface temperature have been greater than the theoretical. For the latter, however, the table of § 64 gives us smaller values the further back we follow the change of state of the Sun. We may therefore state the result of this inquiry as follows: *The surface temperature of the Sun was never very much higher, and in future can never be very much higher than it is at present.*

From the two last propositions it follows that the surface

temperature of a star can be markedly higher than the present surface temperature of the Sun only when the star's mass exceeds the Sun's mass. For a slight difference of temperature the higher value for the star could also, it is true, be explained on the supposition that the Sun has already passed the culmination of its surface temperature, and that the star in question has not yet reached the present density of the Sun. But we may assert in any case that such a difference of temperature admits of a much simpler explanation on the assumption of a greater mass of the star, and that this assumption opens a much wider range for the explanation of high surface temperatures than that of a lesser density of the star, inasmuch as according to the first of the above propositions, a double surface temperature would correspond to a fourfold mass.

Since a rise of the surface temperature of a body at white incandescence requires an increasing predominance of the blue and violet rays in the spectrum, we may infer that those stars whose light appears white or bluish-white in contrast to the yellowish light of the Sun, in consequence of the predominance of the more refrangible rays, (Sirius, Vega) possess a higher surface temperature than the Sun.[1] From the hypotheses here proposed this conclusion then follows:

The masses of the white stars are greater than the mass of the Sun.

§ 67. HYPOTHESES AS TO THE CONSTITUTION OF THE RED STARS.

A gaseous sphere in adiabatic equilibrium, of mass equal to that of the Sun, and of radius one hundred thousand times that of the Sun, would have such a slight mean density that even the rays emitted from the center would suffer only a vanishingly small absorption, inasmuch as the total mass in the layer which such a ray would have to penetrate would amount to only a few hundred kilograms per square meter.

The quantity of heat radiated per unit of time under this

[1] Cf. H. C. VOGEL, "Resultate spectralphotometrischer Untersuchungen," *Berliner Berichte*, Sitzung vom 21. October 1880.

condition of density can depend solely upon the temperature, increasing with a rise of temperature. Under the contraction consequent upon giving out heat the interior heat of the sphere increases in inverse proportion to the radius, and hence during the contraction the quantity of heat radiated per unit of time must also increase so long as the mean density is low enough to approximately satisfy our first condition.

If the mean density later becomes greater so that the direct radiation into space extends inward just to the center, then at this epoch a central nucleus will begin to develop from the particles of which no heat rays will be able to reach out to empty space. With further contraction the radius of this nucleus, thus protected from loss by direct radiation, will at first increase; but later, when the difference between the radius of the nucleus and the whole radius — or depth of the radiating surface layer — amounts to only a small fraction of the whole radius, the radius of the nucleus must again decrease, because the whole radius continually diminishes.

It was shown in §64 that during this last period of development the quantity of heat radiated per unit of time continuously decreased, and since during the first period the radiation at least at first increased, it follows that at some intermediate point the quantity of heat radiated per unit of time must have reached a maximum.

It was shown in the previous paragraph that, although the theoretical surface temperature would constantly increase during this latter period, in consequence of the departure from Mariotte's law the actual surface temperature must begin to fall again after passing a certain culmination point.

The results of §65 indicated that a star always reaches the culmination of its heat radiation earlier than the culmination of its surface temperature. The first corresponds to the epoch of greatest brightness or light-intensity, and the second to the epoch when the color representing the total impression of the emitted light shifts toward the violet end of the spectrum, and when the light appears bluish-white if the star's mass is sufficient. The

Sun perhaps passed the first culmination point at the time when its radius was about the size of the radius of the Earth's orbit, while the last point of culmination corresponds to a condition which in all probability differs but little from the present state.

After passing the first point the luminous intensity decreases while the surface temperature is still rising. With the passage of the second point the surface temperature in turn begins to fall and the color begins to approach the red end of the spectrum again. A star which emits bluish-white light at the culmination of its surface temperature must have appeared red at an earlier epoch, when its surface temperature was far below its maximum value; and similarly it will necessarily appear red once more at a later time, when after passing its maximum the surface temperature has again fallen considerably.

If we divide the stars into three classes according to their surface temperatures, assigning with Vogel[1] the white stars to the first class, the yellow to the second, and the red stars to the third class, we should have to distinguish between two groups or subdivisions within the third class. According to the theory here advanced, we should put in the first subdivision those red stars whose surface temperatures have not yet reached the culmination point; in the second all those red stars whose surface temperatures have already passed their culmination. Since we may assume from §65 that a star always reaches its luminous culmination much earlier than that of its surface temperature, the stars belonging to the first subdivision will necessarily possess predominatingly slight density and high luminous intensity, while those of the second subclass will have great density and slight luminous intensity.

If we may further believe that the development of chemical compounds is favored by greater density in conjunction with relatively low temperature, then we should expect in the spectra of the older and denser stars of the latter subclass the occurrence of the absorption lines or bands which indicate the presence of chemical combinations in the surface layer.

[1] *A. N.*, **84**, 113–123, 1874.

The question might therefore now be raised whether Vogel's subclasses III a and III b (Secchi's III and IV) may not be identical with the two subclasses proposed here on theoretical grounds, and also whether we may not conclude from the peculiar band spectrum of class III b—as well as from the fact that no stars of this group have been observed which are brighter than the fifth magnitude—that these stars belong to those older, denser, and fainter stars which have already passed the culmination of their surface temperature. The reply to these questions must be left to the further researches of spectrum analysis.

As for stars of the third class we might perhaps also distinguish between two subclasses for each of the first and second classes, namely—that of the relatively young stars which have not yet reached the maximum of surface temperature, and that of the older stars which have already passed it. In any case we may infer that the nature of the spectrum of a star depends not only upon the temperature but also upon the density of its surface layer, which increases with age; and that the spectra of two stars of the same surface temperature can be different if their surface layers have unequal densities. Since according to §65 the surface temperature of a star also depends upon its mass, the spectrum must depend simultaneously on the mass and the relative age of the star. The reply to the inquiry whether the supposition of variations in mass and in age would be sufficient for a satisfactory explanation of the varieties of spectra thus far observed must again be left for future spectroscopic researches.

§68. CONJECTURAL CAUSES OF THE PAUCITY OF RED STARS.

If we exchange the two limits of integration in equation (624), we shall obtain for the interval in which the solar radius would decrease from r_0 to r

$$t = \frac{k\, r_0}{(7k-8)\,\sigma_0} \left\{ \left(\frac{r_0}{r}\right)^{\frac{7k-8}{k}} - 1 \right\}, \qquad (636)$$

which, after substituting $k=\frac{5}{3}$ and $\sigma_0=48^m$, becomes

$$t = 6\,504\,000 \left\{ \left(\frac{r_0}{r}\right)^{2.2} - 1 \right\}.$$

For example we should obtain from this $t=23.4$ million years as the time required for the solar radius to contract to one half its present size. According to equation (627), under the same conditions, the interval in which the solar radius diminished from $2r_0$ to r_0 would be about 5.1 million years. Hence the whole duration of the contraction from the size $2r_0$ to $\frac{1}{2}r_0$ would be about 28.5 million years or about twenty times the interval of contraction from $215r_0$ to $2r_0$, which would be by (627) only about 1.4 million years.

Even if the theoretical values calculated in this way must for the reasons given in §66 be regarded as rough approximations, which can claim only an extremely slight degree of accuracy and may differ widely from the true values, nevertheless we may be permitted to infer from the above results that in early times,— for instance when the solar radius was one hundred times as large as at present,— change of condition and decrease in volume of the Sun's mass took place with a vastly greater rapidity than at present, when the condition is nearly stationary.

We may also conclude that the duration of the period in which the Sun as a star had a greater brightness than at present was very short in comparison to the period in which it had and will continue to have a brightness differing only slightly from its present value.

The point of culmination of heat radiation of a star represents a state of relatively rapid transition; the point of culmination of surface temperature, however, represents a state in which the star remains for a comparatively long time.

In equation (636) we should get $t=\infty$ for $r=0$, *i. e.*, if the Sun possessed the properties of a perfect gas, its volume would shrink to zero only after an infinitely long period, and its luminosity would continue forever. Since however an unlimited possibility of increase of density is out of the question we must assume that after a definite finite though very long period the Sun will reach a point at which its luminosity must entirely cease; and

the same must be assumed for every star. In this sense we may speak of a definite period of apparition of a star, just as of a comet or meteorite, even if many hundreds of millions of years may elapse between the first appearance and the final extinction.

The whole period of apparition of a star is on our theory divided into three parts by the culmination of heat radiation and the culmination of surface temperature. During the first interval the quantity of heat radiated per unit of time is constantly on the increase. At the beginning of this interval — when the star was still in the nebular condition — the change took place very slowly on account of the very slight radiation of heat, but later it became very rapid as with increasing density the maximum of brightness was approached. During the second interval the radiation of heat is constantly on the decrease, changing at first rapidly, and later more slowly as the surface temperature approaches its maximum. During the third period both radiation and surface temperature are in steady decline, but the condition changes very slowly throughout the whole period.

The very protracted period of slow genesis is therefore followed by a very short middle interval of rapid changes of condition and this in turn is succeeded by another very protracted period of slow extinction. If we then divide the stars into three classes according to age corresponding to these three stages of development, we shall assign to the first class *A* those stars still in the nebular phase of development; to the second class *B* those in the transient stage of greatest brilliance; and to class *C* those stars which have already entered into the long period of slow extinction. It should be noted in this classification that we refer to relative and not absolute age, since a star of slight mass passes through the successive phases of its development more rapidly than a star of greater mass.

Since the class *B* represents a phase of relatively very brief duration we should expect from the laws of probabilities that the number of the stars simultaneously in this stage would be very small in comparison to the whole number of stars, and also to the number of stars in class *C*.

According to our hypotheses the class *B* would include the younger stars of class III, that is, the red stars which have not yet reached the culmination of their surface temperature. The class *C* would comprise classes I and II and also the older stars of class III which have passed the culmination of surface temperature and have reached a point approximating total extinction.

We cannot however expect with certainty that these last stars should have numerous representatives among the stars at present actually visible, on the one hand because their faintness may have largely caused them to escape observation, and on the other hand because it is quite possible that the whole system of stars is still in a period of relative youth, so that only a few stars of slight mass have already reached the condition immediately preceding extinction.

The results of spectroscopic observations may be regarded as favorable to our hypotheses, inasmuch as Vogel[1] found in a zone of 3702 stars examined 2165 of class I, 1240 of class II, 288 of class III a, and 9 of class III b.

[1] *Publicationen*, Potsdam, Bd. III, 1883.

Minor Contributions and Notes.

ON THE PRESENCE OF HELIUM IN THE EARTH'S ATMOSPHERE, AND ON ITS RELATION TO THE KINETIC THEORY OF GAS.

We have evidence that there is within the Earth a widespread and as yet unexhausted store of helium, from its presence having been detected in many of the hot springs in distant parts of the world which have been examined. It thus became known that this element is, and no doubt has been for ages filtering from that store into the atmosphere. It comes to the atmosphere through hot springs in appreciable quantities, and possibly everywhere through the soil in smaller quantities.

It is also known that helium which reaches the atmosphere uncombined must remain helium, since this gas does not combine with other elements even under circumstances more favorable than those that prevail in the atmosphere.

Helium, which is probably uncombined, has now been detected as a constituent of atmospheric air in the course of the astonishingly delicate experiments which are being made in Professor Ramsay's laboratory in University College, England; but it is found to bear an exceedingly small proportion to the heavier constituents.

That there must be helium in our atmosphere, and that the quantity present must be very small if the helium is uncombined, had been indicated by the Kinetic Theory of Gas (see this Journal for January 1898, p. 30). The recent discovery is accordingly a confirmation in this instance of the deductions which can be made from the kinetic theory.

The kinetic theory indicates that molecules drift away at the boundary of our atmosphere from all its gaseous constituents; but that the number is so small in the case of gases with the density of nitrogen and oxygen that it would probably take many billions of years to effect any observable reduction of the quantity of these gases; whereas with gases whose density is below a certain limit (which differs from one planet to another, and which on the Earth lies somewhere between 2

and 7½) the drifting away will be sufficient to drain off any stock of these gases altogether in a moderate number of years, unless there be some persistent source of supply. When, as in the case of helium, there is such a source of supply, the gas which will be found in the atmosphere at any one time will be that which is making its way upwards by diffusion, from the bottom of the atmosphere, where it enters, to the top where it escapes.

It is possible that a still more minute trace of uncombined hydrogen will be found if the delicacy of the experiments can be carried much further.

Since physicists are now able to detect in atmospheric air the presence of a constituent which is estimated to occupy only a fraction of a millionth of the whole volume, it may not be out of place to call attention to the fact that besides the gaseous constituents of our atmosphere there is also in the air which is accessible to us a minute quantity of carbon and even traces of other solid elements, owing to the swarms of micro-organisms that are everywhere present. Some of these can be seen by the microscope, but those that are beyond its reach must be vastly more numerous. It should be remembered in this connection that a spore that is only the hundredth of a micron across has still sufficient space within that small volume for something like a million of chemical atoms. Now the smallest interval at which two objects can be seen as two with the best microscope most carefully handled is about twenty times the diameter of that spore.

G. JOHNSTONE STONEY.

LONDON, October 11, 1898.

THE PURKINJE PHENOMENON AND THE SPECTRUM OF THE ORION NEBULA.

SINCE returning from India I have read Professor Scheiner's article[1] concerning my observations of variations in the Orion Nebula spectrum. Professor Scheiner did not succeed in confirming my observations, and declared that "the whole appearance recorded by Professor Campbell is nothing more nor less than the 'Purkinje Phenomenon.'"

Such an extremely positive statement as this is evidently unwarranted for several reasons.

[1] This JOURNAL, April 1898, 295–298.

1. It is pure assumption, since Professor Scheiner did not prove it by observations bearing either directly or closely upon the subject.

2. The assumption is erroneous. Professor Runge has shown (this JOURNAL, **8**, 32–36) by observations bearing directly on the question at issue, that *less than a twofold variation* is explained by the Purkinje Phenomenon, whereas the apparent variation observed in the nebular spectrum by myself and by Messrs. Schaeberle, Runge, Aitken, and Wright was from twenty-five to thirtyfold.

3. Professor Scheiner's criticism is based very largely on the assumption that I did not take proper precautions to eliminate the effects of physiological error — an assumption that is erroneous. My published observations show plainly that such precautions were taken, and I venture to say a more careful reading of them would have rendered this entire discussion unnecessary.

In *Astronomy and Astro-Physics* for May 1894, **13**, 388, while discussing the relative brightness of the second (λ4959) and third ($H\beta$) nebular lines for the Trapezium region, I wrote: "As Dr. Huggins has pointed out, 'the second line suffers in apparent brilliancy from its nearness to the brightest line.' With low dispersion it seems considerably fainter than the $H\beta$ line, even in the vicinity of the Trapezium. But when the very bright first line is covered with a heavy micrometer wire, the second line is seen to be fully as bright as the third. *This point was further tested by using two gratings in the first, second, and third orders, with which the second and third lines become very faint and widely separated. By narrowing the slit until the lines were rendered almost invisible, the second line was seen with certainty to be a very little brighter than the third line.*"

The sentences which I have italicized show that the observer was on his guard against physiological effects. By reducing the brightness of the lines until they became "very faint," and later until they "were rendered almost invisible," the second line was seen to be "a very little brighter than the third line," but much fainter than the first line. In a faint outlying region I found the third line to be at least five times as bright as the first line (Professor Runge's estimate was ten times), and the second line was invisible. The use of two gratings in three orders should be a sufficient precaution against peculiarities of the gratings. My notes show that throughout the grating observations, both with wide and with narrow slits, the second line was estimated to be brighter than the third.

This would seem to be sufficient proof that the observer not only realized the difficulty of making accurate visual estimates, *but that he took the proper precautions to eliminate the very effects which Professor Scheiner assumed he did not eliminate*, as well as other subjective effects which Professor Scheiner did not mention.

Further evidence as to the observer's state of mind is afforded on page 494 of my same paper. Concerning the nebula *DM.* — 12°1172 I wrote: "The relative intensities of the light in the three disks (corresponding to three nebular lines) were estimated at 10 : 3 : 7. A wedge photometer of increasing darkness was moved over the eyepiece at right angles to the line joining the three disks; and the fact that the disk at 4861 ($H\beta$) disappeared before the disk at 5007 did, proves that the latter is the brighter."

This nebula is near the Orion Nebula, and the photometer was used on the lines in both. It confirmed the results on the Orion Nebula previously obtained with the grating. The wedge was of neutral tint and its absorption curve would probably be no steeper at $H\beta$ than the absorption curve for the prism.

My observations may be repeated with surprising ease by those who have suitable apparatus; but one who uses a very short collimator, a relatively long view telescope, a weak prism, and a high-power eyepiece will deservedly fail. An observation of this kind made with an inefficient instrument is worth even less than a stellar parallax determined with a ring micrometer.

In asking Professor Scheiner for his estimate of the relative intensities of the lines in the vicinity of star Bond 734 — with which he disclaims power from nature to comply — I was asking him to use the method and notation which are sufficiently common, and which he himself employed in his book on *Spectrum Analysis*. For example, he wrote "Für den Orionnebel findet Vogel als Helligkeitverhältniss der vier Linien 10, 5, 8, 1" (Scheiner's *Die Spectralanalyse*, p. 247).

W. W. CAMPBELL.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

The ASTROPHYSICAL JOURNAL is published monthly except in July and September. The annual subscription price for the United States, Canada, and Mexico is $4.00; for other countries in the Postal Union it is 18 shillings. Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

Wm. Wesley & Sons, 28 Essex St., Strand, London, are sole foreign agents, and to them all European subscriptions should be addressed.

All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

INDEX TO VOLUME VIII.

SUBJECTS.

PAGE

ABSORPTION of Aqueous Vapor and Carbon Dioxide in the Infra-red Spectrum. *H. Rubens* and *E. Aschkinass* - - - - - 176

ANDROMEDA Nebula. *E. E. Barnard* - - - - - - - 226

Edward C. Pickering - - - - - 262

AQUEOUS Vapor, Absorption and Emission in the Infra-red Spectrum. *H. Rubens* and *E. Aschkinass* - - - - - - - 176

Y AQUILAE, Supposed Variable Star. *Edward C. Pickering* - - 57

ARC, Shading of H and K and some other Lines in Spectrum of. *L. E. Jewell* - - - - - - - - - - - - - 51

AREQUIPA Station, Position of the. *Winslow Upton* - - - 249

ASTEROIDS, Rotation of. *Henry M. Parkhurst* - - - - 245

ASTRONOMICAL and Physical Conference at Harvard College Observatory. *George E. Hale* - - - - - - - - - 54

Instruments, Founding of. *David P. Todd.* - - - - 254

ASTROPHYSICAL Observatory, Washington, Recent Bolographic Results. *C. G. Abbot* - - - - - - - - - 250

ATLAS Stellarum Variabilium, Chart from. *J. G. Hagen, S. J.* - 160

ATMOSPHERE of Hydrogen Surrounding Wolf-Rayet Star *DM.* +30°3639. *James E. Keeler* - - - - - - - - - 113

New Gases in the Earth's. *Edwin B. Frost* - - - - - 121

On the Presence of Helium in Earth's. *G. Johnstone Stoney* - 316

ATMOSPHERIC Disturbance, Effect on Telescopic Definition. *G. W. Hough* - - - - - - - - - - - - - - 236

β AURIGAE, K Lines of. *Antonia C. Maury* - - - - - - 173

BLUE Hill Meteorological Observatory. *A. Lawrence Rotch* - - 241

BOLOGRAPHIC Results from the Astrophysical Observatory, Washington. *C. G. Abbot* - - - - - - - - - - - 250

BRUCE 24-inch Photographic Telescope, Distortion of Photographs made with the. *H. H. Turner* - - - - - - - - 252

CARBON Band-Spectrum, Series in the. *T. N. Thiele* - - - - 1

CARBON Dioxide, Absorption and Emission in the Infra-red Spectrum. *H. Rubens* and *E. Aschkinass* - - - - - - - - 176

CATALOGUE of North Polar Distances, Proposed. *J. F. Hayford* - 243

CELESTIAL Gaseous Bodies, Constitution of. *A. Ritter* - - - 293

CHART from the Atlas Stellarum Variabilium. *J. G. Hagen, S.J.* - 160

CHROMOSPHERE Line near K. *Lewis E. Jewell* - - - - 119

PAGE

CLASSIFICATION of Spectra of Long Period Variables. *M. Fleming* 233
CLUSTERS, Variable Stars in. *Edward C. Pickering* - - - 257
S. I. Bailey - - - - - 233
COMET, Swift (I, 1892). *W. H. Pickering* - - - - - 255
COMET I, 1898, Photographed with the Crossley Reflector. *James E. Keeler* - - - - - - - - - - - 287
CONCAVE Grating, Letter regarding. *H. Kayser* - - - - 263
Notes on the. *S. A. Mitchell* - - - - - - - - 102
CONFERENCE of Astronomers and Astrophysicists, Proceedings of Second - - - - - - - - - - - 229
at the Harvard College Observatory. *George E. Hale* - 54, 193
CONSTITUTION of Gaseous Celestial Bodies. *A. Ritter* - - - 293
CORONA, Method of Photographing Spectrum of, in Different Regions. *David P. Todd* - - - - - - - - - - - 253
CROSSLEY Reflector Photographs of Comet I, 1898. *James E. Keeler* 287
61¹ and 61² Cygni, Parallaxes of. *Herman S. Davis* - - - 246
DIRECT Grating Spectroscope. *Charles Lane Poor* - - - - 235
DISTORTION of Photographs made with the 24-inch Bruce Telescope. *H. H. Turner* - - - - - - - - - - - 252
DOUBLE Star Work of the Flower Observatory. *C. L. Doolittle* - 247
χ DRACONIS, Variable Velocity in the Line of Sight of. *W. W. Campbell* - - - - - - - - - - - - 292
ECHELON Spectroscope. *A. A. Michelson* - - - - - - 37
EFFECT of Atmospheric Disturbance on Telescopic Definition. *G. W. Hough* - - - - - - - - - - - - 236
of Pressure on Wave-length, Wilsing's Article on. *Charles Godfrey* - - - - - - - - - - - - - 114
EFFECTIVE Insulation for Mercurial Horizons. *David P. Todd* - 253
EMISSION of Aqueous Vapor and Carbon Dioxide in the Infra-red Spectrum. *H. Rubens* and *E. Aschkinass* - - - - 176
FIFTH Type Stars in the Magellanic Clouds. *M. Fleming* - - 232
"FLASH" Spectrum Photograph. *T. W. Backhouse* - - - 198
by K. D. Naegamvala - - - 120
FLOWER Observatory, Double Star Work of. *C. L. Doolittle* - - 247
FORMULA, Interpolation, for the Prismatic Spectrum. *J. Hartmann* 218
FOUNDING of Astronomical Instruments. *David P. Todd* - - 254
FOURTH Type Stars, Spectra of. *George E. Hale* - - - - 237
FROST, Edwin Brant, Election of, as Professor of Astrophysics at the Yerkes Observatory. *George E. Hale* - - - - - 59
GASES, New, in the Earth's Atmosphere. *Edwin B. Frost* - - 121
GASEOUS Celestial Bodies, Constitution of. *A. Ritter* - - - 293
GRATING, Concave, Notes on the. *S. A. Mitchell* - - - - 102

PAGE

Concave, Letter regarding. *H. Kayser* - - - - - - 263
Spectroscope, Direct. *Charles Lane Poor* - - - - - 235
GREAT Velocities of Stars in the Line of Sight. *W. W. Campbell* - 157
HARVARD Conference - - - - - - - - - 54, 193, 229
HELIUM in the Earth's Atmosphere. *G. Johnstone Stoney* - - 316
HORIZONS, Insulation of Mercurial. *David P. Todd* - - - 253
HYDROGEN Atmosphere Surrounding the Wolf-Rayet Star $DM+30°3639$. *James E. Keeler* - - - - - - - - - 113
INFRA-RED Spectrum of Aqueous Vapor and Carbon Dioxide. *H. Rubens* and *E. Aschkinass* - - - - - - - - - 176
INTERPOLATION Formula for the Prismatic Spectrum. *J. Hartmann* 218
INTENSITIES of the Lines in the Spectrum of the Orion Nebula. *C. Runge* - - - - - - - - - - - - - - 32
INSULATION of Mercurial Horizons. *David P. Todd* - - - 253
LATITUDES, Investigations of Zenith Telescope. *G. C. Comstock* - 230
LEONID Meteors. *Edward C. Pickering* - - - - - - - 319
o LEONIS, Variable Velocity in the Line of Sight of. *W. W. Campbell* - - - - - - - - - - - - - - 291
LICK Observatory Spectrograph. *W. W. Campbell* - - - 123
LIGHT, Zodiacal. *Arthur Searle* - - - - - - - - 244
Name for Chief Nebular Constituent. *Margaret L. Huggins* - 54
K LINES of β Aurigae. *Antonia C. Maury* - - - - - 173
LINE in Chromosphere near K. *Lewis E. Jewell* - - - - 119
of Sight Motions of Stars. *H. C. Lord* - - - - - 65
of Sight Velocities of Stars. *W. W. Campbell* - - - - 157
of Sight Velocity of χ Draconis, Variable. *W. W. Campbell* - 292
of Sight Velocity of o Leonis, Variable. *W. W. Campbell* - - 291
of Sight Velocity of η Pegasi, Variable. *W. W. Campbell* - - 159
LINES, H and K, Shading of. *L. E. Jewell* - - - - - 51
Intensities of, in the Spectrum of the Orion Nebula. *C. Runge* 32
LONG Period Variables, Classification of Spectra of. *M. Fleming* - 233
MAGELLANIC Clouds, Fifth Type Stars in. *M. Fleming* - - - 232
MERCURIAL Horizons, Insulation of. *David P. Todd* - - - 253
MERIDIAN Observations for Stellar Parallax. *Albert S. Flint* - - 234
METEOROLOGICAL Observatory, Blue Hill. *A. L. Rotch* - - 241
METEORS, November. *Edward C. Pickering* - - - - - 115
MCMILLIN Observatory Observations of Stellar Motions in the Line of Sight. *H. C. Lord* - - - - - - - - - 65
MILLS' Spectrograph of the Lick Observatory. *W. W. Campbell* - 123
MOON, Probable Range of Temperature on the. *F. W. Very*, I, 199; II, 265
MOTION of Stars. *W. H. S. Monck* - - - - - - - 28
MOTIONS of Stars in the Line of Sight. *H. C. Lord* - - - 65

PAGE

NAEGAMVALA, K.D. Photograph of "Flash" Spectrum at the Eclipse, January 21, 1898 - - - - - - - - - - 120
NAME for Source of Chief Nebular Rays. *Margaret L. Huggins* - 54
NEBULA of Andromeda. *E. E. Barnard* - - - - - 226
Edward C. Pickering - - - - 262
NEBULA, Intensities of Lines in the Spectrum of the Orion. *C. Runge* 32
of Orion, Purkinje Phenomenon in Spectrum of. *W. W. Campbell* 317
NEW Gases in the Earth's Atmosphere. *Edwin B. Frost* - - 121
NORTH Polar Distances, Proposed Catalogue of. *J. F. Hayford* - 243
NOVEMBER Meteors. *Edward C. Pickering* - - - - - 115
OBSERVATIONS on the Absorption and Emission of Aqueous Vapor and Carbon Dioxide in the Infra-red Spectrum. *H. Rubens* and *E. Aschkinass* - - - - - - - - - - 176
Solar, Made at the Roman College during the First Half of 1898. *P. Tacchini* - - - - - - - - - - - 223
ORION Nebula, Intensities of Lines in Spectrum of. *C. Runge* - - 32
Nebula, Purkinje Phenomenon in Spectrum of. *W. W. Campbell* - - - - - - - - - - - 317
OXYGEN, Series Spectrum of. *C. Runge* and *F. Paschen* - - - 70
PARALLAX, Meridian Observations for Stellar. *Albert S. Flint* - 234
PARALLAXES of 61^1 and 61^2 Cygni. *Herman S. Davis* - - - 246
PECULIAR Spectra, Stars Having. *Edward C. Pickering* - - 116
U PEGASI, Variable Star. *G. W. Myers* - - - - - - - 163
η PEGASI, Variable Velocity in the Line of Sight. *W. W. Campbell* 159
PERSONAL Equation in Transit Observations. *Arthur Searle* - - 229
PHOTOGRAPH of "Flash" Spectrum. *T. W. Backhouse* - - 198
of the "Flash" Spectrum by Professor K. D. Naegamvala, at the Eclipse of January 21, 1898. - - - - - - - - 120
PHOTOGRAPHIC Researches near the North Pole. *Harold Jacoby* - 242
PHOTOGRAPHING the Spectrum of the Corona in Different Regions. *David P. Todd* - - - - - - - - - - - 253
PHOTOGRAPHS made with the Bruce 24-inch Photographic Telescope, Distortion of. *H. H. Turner* - - - - - - - - 252
of Comet I, 1898, made with the Crossley Reflector. *James E. Keeler* - - - - - - - - - - - - - 287
Portrait-Lens. *E. E. Barnard* - - - - - - - 240
PLANET D Q, Witt's. *Edward C. Pickering* - - - - - - 261
POLE of the Heavens, Photographic Researches near the. *Harold Jacoby* - - - - - - - - - - - - - 242
PORTRAIT-LENS Photographs. *E. E. Barnard* - - - - - 240
POSITION of the Arequipa Station. *Winslow Upton* - - - 249
PRECISION, Founding of Instruments of. *David P. Todd* - - 254

PAGE

PRESSURE, Effect of, on Wave-length, Wilsing's Article on. *Charles Godfrey* - - - - - - - - - - - - 114
PRISMATIC Spectrum, Interpolation Formula for. *J. Hartmann* - 218
PROCEEDINGS of the Second Conference of Astronomers and Astrophysicists - - - - - - - - - - - - 229
PURKINJE Phenomenon in Spectrum of Orion Nebula. *W. W. Campbell* - - - - - - - - - - - - - 317
RANGE of Temperature on the Moon. *F. W. Very* I, 199; II, 265
REFLECTOR, Crossley, Photographs of Comet I, 1898. *James E. Keeler* - - - - - - - - - - - - - 287
RESEARCHES, Photographic, near the North Pole. *Harold Jacoby* - 242
RESOLUTION into Series of the Third Band of the Carbon Band-Spectrum. *T. N. Thiele* - - - - - - - - - - 1
ROMAN COLLEGE Solar Observations during First Half of 1898. *P. Tacchini* - - - - - - - - - - - - 223
ROTATION of Asteroids. *Henry M. Parkhurst* - - - - - 245
SECCHI'S Fourth Type Stars. *George E. Hale* - - - - - 237
SELENIUM, Series Spectrum of. *C. Runge* and *F. Paschen* - - 70
SERIES in the Carbon Band-Spectrum. *T. N. Thiele* - - - 1
Spectra of Oxygen, Sulphur, and Selenium. *C. Runge* and *F. Paschen* - - - - - - - - - - - - - 70
SHADING of the H and K and some other Lines in the Spectrum of the Sun, and Arc. *L. E. Jewell* - - - - - - - - 51
SHORT Period Variable Stars. *Edward C. Pickering* - - - 55
SOLAR Observations made at the Roman College during the First Half of 1898. *P. Tacchini* - - - - - - - - - 223
SPECIMEN Chart from the *Atlas Stellarum Variabilium*. *J. G. Hagen, S.J.* - - - - - - - - - - - - 160
SPECTRA of Long Period Variables, Classification of. *M. Fleming* - 233
of Stars of Secchi's Fourth Type. *George E. Hale* - - - 237
Series, of Oxygen, Sulphur, and Selenium. *C. Runge* and *F. Paschen* - - - - - - - - - - - - - 70
and Proper Motion of Stars. *W. H. S. Monck* - - - - 28
Stars Having Peculiar. *Edward C. Pickering* - - - - 116
SPECTROGRAPH of the Lick Observatory. *W. W. Campbell* - - 123
SPECTROSCOPE, Direct Grating. *Charles Lane Poor* - - - 235
Echelon. *A. A. Michelson* - - - - - - - - - 37
SPECTRUM, Absorption and Emission, of Aqueous Vapor and Carbon Dioxide in the Infra-red. *H. Rubens* and *E. Aschkinass* - 176
Photograph of "Flash." *T. W. Backhouse* - - - - - 198
Prismatic, Interpolation Formula for. *J. Hartmann* - - 218
of the Orion Nebula, Intensities of Lines in. *C. Runge* - - 32

PAGE

of the Corona, Method of Photographing in Numerous Distinct Regions. *David P. Todd* - - - - - - - - - 253
of the "Flash," Photograph of, by K. D. Naegamvala - - 120
of the Orion Nebula, Purkinje Phenomenon in. *W. W. Campbell* - - - - - - - - - - - - 317
of the Sun and Arc, Shading of H and K and other Lines in. *L. E. Jewell* - - - - - - - - - - 51
Series in the Carbon Band. *T. N. Thiele* - - - - - 1
STAR, Double, Work of the Flower Observatory. *C. L. Doolittle* - 247
DM + 30° 3639, Hydrogen Atmosphere of. *James E. Keeler* - 113
U Pegasi, Variable. *G. W. Myers* - - - - - - - 163
Supposed Variable, Y Aquilae. *Edward C. Pickering* - - 57
STARS, Classification of Spectra of Long Period, Variable. *M. Fleming* 233
having Peculiar Spectra. *Edward C. Pickering* - - - 116
of the Fifth Type in the Magellanic Clouds. *M. Fleming* - - 232
of Secchi's Fourth Type. *George E. Hale* - - - - 237
Variable, in Clusters. *S. I. Bailey* - - - - - - 233
Variable, in Clusters. *Edward C. Pickering* - - - - 257
Variable, of Short Period. *Edward C. Pickering* - - - 55
Spectra and Proper Motion of. *W. H. S. Monck* - - - 28
with Great Velocities in the Line of Sight. *W. W. Campbell* - 157
STELLAR Motions in the Line of Sight. *H. C. Lord* - - - 65
Parallax, Meridian Observations for. *Albert S. Flint* - - 234
SULPHUR, Series Spectrum of. *C. Runge* and *F. Paschen* - - 70
SUN, Shading of H and K and some other Lines in Spectrum of. *L. E. Jewell* - - - - - - - - - - - - 51
SWIFT'S Comet (I. 1892). *W. H. Pickering* - - - - - - 255
TELESCOPE, Bruce 24-inch, Distortions of Photographs made with the. *H. H. Turner* - - - - - - - - - - - - 252
TELESCOPIC Definition Affected by Atmospheric Disturbance. *G. W. Hough* - - - - - - - - - - - - - - 236
TEMPERATURE on the Moon, Probable Range of. *F. W. Very*, I, 199; II, 265
TRANSIT Observations, Personal Equation in. *Arthur Searle* - - 229
VARIABLE STAR U Pegasi. *G. W. Myers* - - - - - - 163
Supposed, Y Aquilae. *Edward C. Pickering* - - - - 57
VARIABLE STARS in Clusters. *S. I. Bailey* - - - - - - 233
in Clusters. *Edward C. Pickering* - - - - - - - 257
of Short Period. *Edward C. Pickering* - - - - - 55
of Long Periods, Classification of Spectra of. *M. Fleming* - 233
Velocity of χ Draconis in the Line of Sight. *W. W. Campbell* - 292
Velocity of ο Leonis in the Line of Sight. *W. W. Campbell* - 291
Velocity of η Pegasi in the Line of Sight. *W. W. Campbell* - 159

PAGE

VELOCITY of η Pegasi in the Line of Sight, Variable. *W. W. Campbell* 159
Variable of χ Draconis. *W. W. Campbell* - - - - - 292
Variable of o Leonis. *W. W. Campbell* - - - - - 291
VELOCITIES of Stars in the Line of Sight. *W. W. Campbell* - - 157
WAVE-LENGTH, Effect of Pressure on, Wilsing's Article on. *Charles Godfrey* - - - - - - - - - - - - 114
WILSING'S Article on Effect of Pressure on Wave-length. *Charles Godfrey* - - - - - - - - - - - - 114
WITT'S Planet D Q. *Edward C. Pickering* - - - - - 261
WOLF-RAYET Star $DM+30^\circ$ 3639, Hydrogen Atmosphere of. *James E. Keeler* - - - - - - - - - - - - 113
ZEEMAN Effect, Notes on. *J. S. Ames, R. F. Earhart,* and *H. M. Reese* 48
ZENITH Telescope Latitudes, Investigations of. *G. C. Comstock* - 230
ZODIACAL Light. *Arthur Searle* - - - - - - - - - 244

INDEX TO VOLUME VIII.

AUTHORS.

PAGE

ABBOTT, C. G. Recent Bolographic Results from the Astrophysical Observatory at Washington - - - - - - - - - 250

AMES, J. S., R. F. EARHART, and H. M. REESE. Notes on the Zeeman Effect - - - - - - - - - - - - - 48

ASCHKINASS, E., and H. RUBENS. Observations on the Absorption and Emission of Aqueous Vapor and Carbon Dioxide in the Infra-red Spectrum - - - - - - - - - - 176

BACKHOUSE, T. W. Photograph of "Flash" Spectrum - - - 198

BAILEY, SOLON I. Variable Stars in Clusters - - - - - - 233

BARNARD, E. E. Portrait-Lens Photographs - - - - - - 240

The Great Nebula of Andromeda - - - - - - - - 226

CAMPBELL, W. W. Some Stars with Great Velocities in the Line of Sight - - - - - - - - - - - - - - 157

The Mills Spectrograph of the Lick Observatory - - - 123

The Variable Velocity of η Pegasi in the Line of Sight - - 157

The Variable Velocity of o Leonis in the Line of Sight - - 291

The Variable Velocity of χ Draconis in the Line of Sight - - 292

The Purkinje Phenomenon and the Spectrum of the Orion Nebula 317

COMSTOCK, GEORGE C. Some Investigations Relating to Zenith Telescope Latitudes - - - - - - - - - - - 230

DAVIS, HERMAN S. Remarks Regarding the Parallaxes of 61^1 and 61^2 Cygni and the Probable Physical Connection of these Two Stars 246

DOOLITTLE, C. L. The Double Star Work of The Flower Observatory, University of Pennsylvania - - - - - - - - 247

EARHART, R. F., J. S. AMES, and H. M. REESE. Notes on the Zeeman Effect - - - - - - - - - - - - - 48

FLEMING, M. Stars of the Fifth Type in the Magellanic Clouds - 232

Classification of the Spectra of Variable Stars of Long Period - 233

FLINT, ALBERT S. Meridian Observations for Stellar Parallax - 234

FROST, EDWIN B. Notes on New Gases in the Earth's Atmosphere - 121

GODFREY, CHARLES. Note on Professor Wilsing's Article on the Effect of Pressure on Wave-length - - - - - - 114

HAGEN, J. G., S. J. A Specimen Chart from the Atlas Stellarum Variabilium - - - - - - - - - - - - - 160

HALE, GEORGE E. Astronomical and Physical Conference at the Harvard College Observatory - - - - - - - - - 54

PAGE

Election of Edwin B. Frost as Professor of Astrophysics at the Yerkes Observatory - - - - - - - - - - 59
The Harvard Conference - - - - - - - - - - 193
On the Spectra of Stars of Secchi's Fourth Type - - - 237
HARTMANN, J. A Simple Interpolation Formula for the Prismatic Spectrum - - - - - - - - - - - - 218
HAYFORD, J. F. A Proposed Catalogue of North Polar Distances - 243
HOUGH, G. W. The Effect of Atmospheric Disturbance on Telescopic Definition - - - - - - - - - - - 236
HUGGINS, MARGARET L. "Teach me how to Name the .... Light" 54
JACOBY, HAROLD. Photographic Researches near the Pole of the Heavens - - - - - - - - - - - - - 242
JEWELL, LEWIS E. A Chromosphere Line near K - - - - - 119
The Structure of the Shading of the H and K and some other Lines in the Spectrum of the Sun and Arc - - - - - 51
KAYSER, H. Letter regarding Concave Grating - - - - - 263
KEELER, JAMES E. The Hydrogen Atmosphere Surrounding the Wolf-Rayet Star, $DM + 30^\circ$ 3639 - - - - - - 113
Photographs of Comet I, 1898 (Brooks), made with the Crossley Reflector of the Lick Observatory - - - - - - - 287
LORD, H. C. Some Observations on Stellar Motions in the Line of Sight made at the Emerson McMillin Observatory - - 65
MAURY, ANTONIA C. The K Lines of β Aurigae - - - - 173
MICHELSON, A. A. The Echelon Spectroscope - - - - - 37
MITCHELL, S. A. Notes on the Concave Grating - - - - 102
MONCK, W. H. S. The Spectra and Proper Motion of Stars - - 28
MYERS, G. W. The Variable Star U Pegasi - - - - - - 163
PARKHURST, HENRY M. Rotation of Asteroids - - - - - 245
PASCHEN, F., and C. RUNGE. On the Series Spectra of Oxygen, Sulphur, and Selenium - - - - - - - - - - 70
PICKERING, EDWARD C. Nebula in Andromeda - - - - - 262
Stars Having Peculiar Spectra - - - - - - - - - 116
The Supposed Variable Star, Y Aquilae - - - - - - 57
The November Meteors - - - - - - - - - - 115
Variable Stars of Short Period - - - - - - - - - 55
Variable Stars in Clusters - - - - - - - - - - 257
Witt's Planet D Q - - - - - - - - - - - 261
PICKERING, W. H. Swift's Comet (I, 1892) - - - - - - 255
POOR, CHARLES LANE. The Direct Grating Spectroscope - - 235
REESE, H. M., J. S. AMES, and R. F. EARHART. Notes on the Zeeman Effect - - - - - - - - - - - - - 48
RITTER. A. On the Constitution of Gaesous Celestial Bodies - - 293

PAGE

ROTCH, A. LAWRENCE. A Brief Account of the Work of the Blue Hill Meteorological Observatory - - - - - - - - 241

RUBENS, H., and H. ASCHKINASS. Observations on the Absorption and Emission of Aqueous Vapor and Carbon Dioxide in the Infra-red Spectrum - - - - - - - - - - 176

RUNGE, C. On the Relative Intensities of the Lines in the Spectrum of the Orion Nebula - - - - - - - - - - 32

RUNGE, C., and F. PASCHEN. On the Series Spectra of Oxygen, Sulphur, and Selenium - - - - - - - - - - 70

SEARLE, ARTHUR. The Zodiacal Light - - - - - - - - 244

Personal Equation in Transit Observations - - - - - 229

STONEY, G. JOHNSTONE. On the Presence of Helium in the Earth's Atmosphere, and on Its Relation to the Theory of Gas - - 316

TACCHINI, P. Résumé of Solar Observations made at the Royal Observatory of the Roman College during the First Half of 1898 - - - - - - - - - - - - - - - 223

THIELE, T. N. Resolution into Series of the Third Band of the Carbon Band Spectrum - - - - - - - - - - - 1

TODD, DAVID P. On a Practical Method of Photographing the Spectrum of the Corona in Numerous Distinct Regions - - - 253

On an Effective Insulation of Mercurial Horizons - - - 253

On the Founding of Astronomical and Other Instruments of Precision - - - - - - - - - - - - - - 254

TURNER, H. H. The Distortion of Photographs made with the Bruce 24-inch Photographic Telescope - - - - - - - - 252

UPTON, WINSLOW. The Position of the Arequipa Station of the Harvard College Observatory - - - - - - - - 249

VERY, FRANK W. The Probable Range of Temperature on the Moon - - - - - - - - - - I, 199; II, 265

GENERAL LIBRARY,
UNIV. OF MICH.
8 JAN

VOLUME VIII NUMBER 5

THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

DECEMBER, 1898

EDITORS

GEORGE E. HALE
Director of the Yerkes Observatory

JAMES E. KEELER
Director of the Lick Observatory

ASSISTANT EDITORS

J. S. AMES
Johns Hopkins University

W. W. CAMPBELL
Lick Observatory

HENRY CREW
Northwestern University

E. B. FROST
Yerkes Observatory

ERNEST F. NICHOLS
Dartmouth College

F. L. O. WADSWORTH
Yerkes Observatory

ASSOCIATE EDITORS

M. A. CORNU
École Polytechnique, Paris

N. C. DUNÉR
Astronomiska Observatorium, Upsala

WILLIAM HUGGINS
Tulse Hill Observatory, London

P. TACCHINI
Osservatorio del Collegio Romano, Rome

H. C. VOGEL
Astrophysikalisches Observatorium, Potsdam

C. S. HASTINGS
Yale University

A. A. MICHELSON
University of Chicago

E. C. PICKERING
Harvard College Observatory

H. A. ROWLAND
Johns Hopkins University

C. A. YOUNG
Princeton University

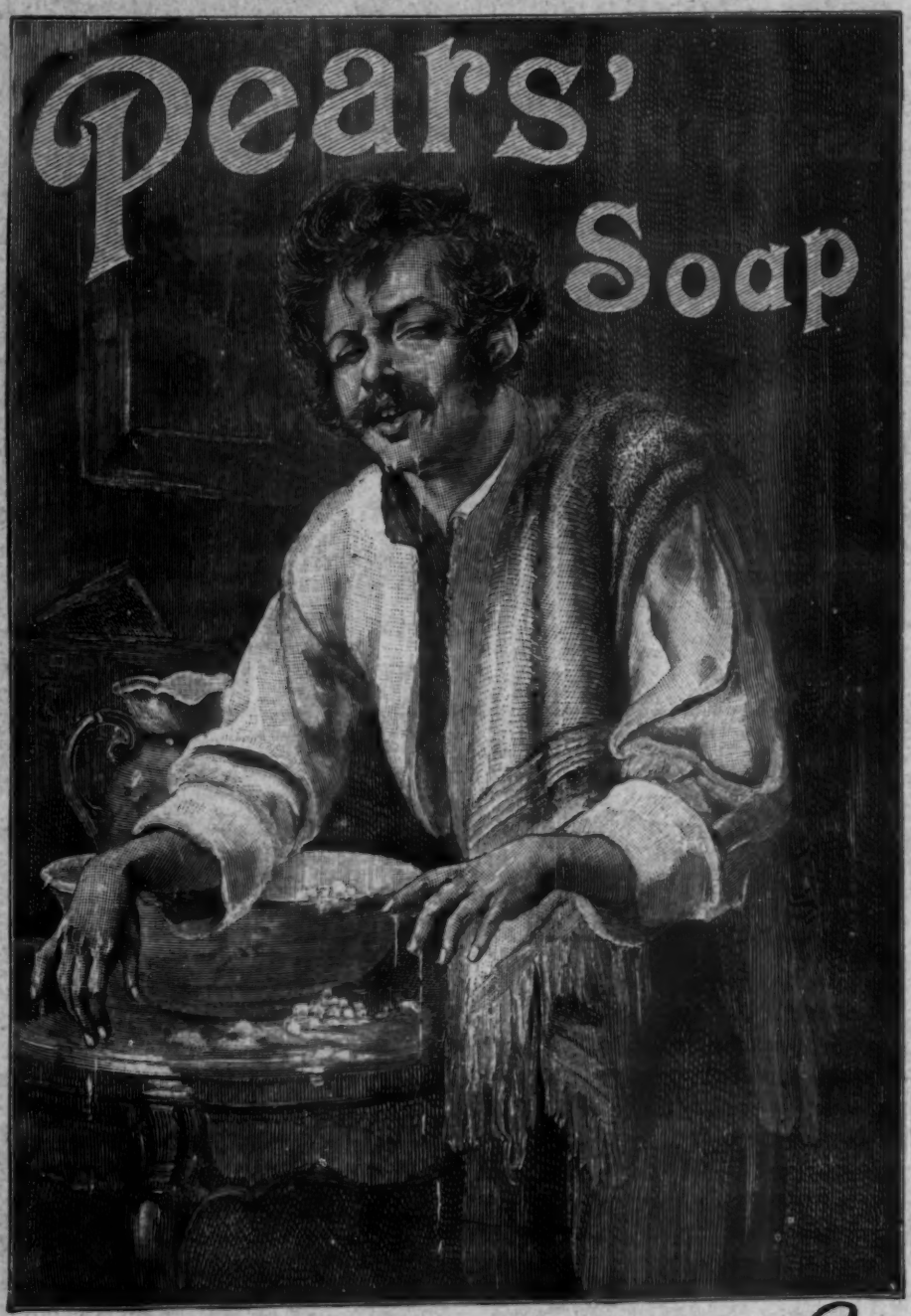
CHICAGO

The University of Chicago Press

WILLIAM WESLEY & SON, 28 Essex St., Strand, London
Sole Foreign Agents

SUBSCRIPTION, FOUR DOLLARS SINGLE NUMBERS, FIFTY CENTS

Copyright 1898 by The University of Chicago



Where's that towel?

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. VIII DECEMBER 1898 NO. 5

THE PROBABLE RANGE OF TEMPERATURE ON THE MOON. II. FRANK W. VERY 265

PHOTOGRAPHS OF COMET I, 1898 (BROOKS), MADE WITH THE CROSSLEY REFLECTOR OF THE LICK OBSERVATORY - - JAMES E. KEELER 287

THE VARIABLE VELOCITY OF o LEONIS IN THE LINE OF SIGHT W. W. CAMPBELL 291

THE VARIABLE VELOCITY OF χ DRACONIS IN THE LINE OF SIGHT W. W. CAMPBELL 292

ON THE CONSTITUTION OF GASEOUS CELESTIAL BODIES - A. RITTER 293

MINOR CONTRIBUTIONS AND NOTES:

On the Presence of Helium in the Earth's Atmosphere, and on Its Relation to the Kinetic Theory of Gas, G. JOHNSTONE STONEY, 316; *The Purkinje Phenomenon and the Spectrum of the Orion Nebula*, W. W. CAMPBELL, 317.

The ASTROPHYSICAL JOURNAL is published monthly except in July and September. Annual subscription, $4.00; foreign, 18 shillings. *Wm. Wesley & Son, 28 Essex Street, Strand, London*, are sole foreign agents and to them all European subscriptions should be addressed. All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

[Entered at the Post Office at Chicago, Ill., as second-class matter.]

What is Dixson's Subject Index to Fiction?

"It is far and away the best and most practical, up-to-date index to historical novels yet published, and is indispensable to public libraries and purchasing committees."—*Edward W. Hall, Librarian of Colby University.*

"An excellent thing well done."—*The Outlook.*

"It is a time-saver that will be appreciated by writers, authors, and readers."—*New York Observer.*

"It is an excellent piece of work. There is no reason why it should not become as much of a standard as Poole's Index."—*The Chicago Tribune.*

"The lists are surprisingly full and accurate. In the bibliographical field few more useful books have appeared this year."—*Philadelphia Book News.*

"Should find a place on every bookman's desk."—*The Bookman.*

"Every student and every writer will feel indebted to the Associate Librarian of the Chicago University."—*The New York Commercial Advertiser.*

"This INDEX will prove a most valuable and delightful guide. It is easy to see also of what special help the work will be in the hands of every pastor, college instructor, librarian, or bookseller "—*Pacific Baptist.*

"Your INDEX has already been of great service to readers of this library and is destined to be used a great deal more."—*R. C. Davis, Librarian of University of Michigan.*

"I am more and more delighted with your INDEX as I use it in connection with my classes."—*C. L. Williams, Professor of English Literature, Denison University.*

"I congratulate you on the service you have rendered readers in this publication."—*Charles C. Soule, Boston Book Co.*

"SUBJECT INDEX TO FICTION promises to win a respected place on the shelves to which such books of reference are assigned."—*The New York Tribune.*

"Your INDEX improves on acquaintance. I never knew what the world of fiction really was before I studied this methodical manual."—*Dr. Charles J. Baldwin, Pastor Granville (O.) Baptist Church.*

"I am experiencing great pleasure and profit from the use of your INDEX. I have recommended it most heartily to our students."—*Dr. J. D. S. Riggs, President of Ottawa University.*

PRICE, ENGLISH BUCKRAM, $2.00 AND POSTAGE

ADDRESS

ZELLA ALLEN DIXSON, A.M.,

Associate Librarian of the University of Chicago,

CHICAGO, ILLINOIS

Astronomical Photographs

On account of the frequent requests received at the Yerkes Observatory for lantern slides and prints from astronomical photographs, it has been thought advisable to make provision for supplying the very considerable demand. Mr. G. Willis Ritchey, Optician of the Observatory, who has had wide experience in making and copying astronomical negatives, has undertaken to furnish such photographs at moderate expense. He is prepared to supply lantern slides, transparencies, and paper prints from any of the negatives in the collection of the Yerkes Observatory.

Among the subjects available at the present time may be mentioned: Professor Hale's photographs of prominences, faculæ and other solar phenomena, and of stellar spectra; Professor Barnard's portrait-lens photographs of the Milky Way, nebulæ, comets, and meteors; Professor Burnham's photographs of the Moon, Winter and Summer views of Mt. Hamilton and the Lick Observatory; Mr. Ellerman's photographs of the buildings and instruments of the Yerkes Observatory; and Mr. Ritchey's Kenwood Observatory photographs of the Moon.

A more complete list of subjects may be had on application to G. WILLIS RITCHEY, Yerkes Observatory, Williams Bay, Wisconsin, *to whom all orders should be addressed.*

BEACON LIGHTS.

Busy Man's Library.

SEND FOR TERMS.

The clearest statement of the greatest men and epochs that have made our civilization.—S. D. Fess, Prof. History, Ada (O.) Normal College.

No library is complete without it.—*J. A. Shawan, State Supt. Pub. Instruction, Columbus, O.*

Every sentence from the pen of Dr. Lord is worth attention. . . . Every library would be enriched by the unique productions of this rare genius.—*Prof. Geo. K. Morris, D.D., School of Theology, Boston University.*

In its department I know of nothing finer. Here epochs are *men* and history is *life*. Faultless in style, in subject-matter comprehensive, in the interpretation of events accurate, and in description most charming.—*S. D. Faust, D.D., Prof. Church History, Union Biblical Seminary.*

Many owe their enthusiasm in the study of history to Dr. Lord.—*Francis L. Patton, D.D., Pres. Princeton College.*

He has inspired large numbers of thoughtful young men to historical study.—*Andrew D. White, ex-Pres. Cornell Univ.*

Without strain on the purse it widens the intellectual horizon Even read as RECREATION, it still has an educative and stimulating force not elsewhere found.

Many subscribers growing enthusiastic double their enjoyment by getting up a social reading club. Keen ones discover a congenial and lucrative *business* in its wide introduction, noting that every set placed creates further demand.

"I am getting full value for my monthly payments in the *current reading*, besides enriching my library for future refreshment or reference." For particulars write to U. C.

FORDS, HOWARD, & HULBERT, 47 E. 10th St., New York.

Mothers Teach Your Boys

W. H. Meadowcroft

Prof. Houston

Dr. Kennelly

ELECTRICITY. Sooner or later it will be of value to them. Secure the best instruction books. A knowledge of electricity is valuable in daily life.

A. B. C. OF ELECTRICITY.

By W. H. MEADOWCROFT. 1 vol., 12mo., cloth, illustrated. Mr. Thos. A Edison endorsed it. 62 thousand men and boys now own this famous book and **inventors have graduated from it.** Sent post-paid for 50c.

ELECTRICITY MADE EASY.

By Prof. EDWIN J. HOUSTON and Dr. A. E. KENNELLY. 350 pages, 12mo., cloth, gilt. 250 pictures. Full index. Written in simple language and with copious illustrations descriptive of the whole science. A magnificent book for boys and all interested in electricity. Latest facts, latest methods, latest machines. Sent post-paid for $1.50.

HOUSTON'S POCKET ELECTRICAL DICTIONARY.

Just published. Contains every word and term known in the science. 11,000 words and 15,000 definitions, including 6,000 new words which have come into use since 1894 and not to be found in any other work. Encyclopedic in character. It is a liberal education to know the contents of this standard work by Prof. EDWIN J. HOUSTON, the authority on the subject. 1 vol., 32mo., 950 pages, cloth, gilt, $2.50; full leather, gold edges, $3.00. Sent post-paid on receipt of price.

All three books sent post-paid for $4.00. Any or all make a most acceptable Xmas Gift.

AMERICAN TECHNICAL BOOK CO., 45 Vesey Street, New York.

THE

Botanical Gazette

Edited by JOHN M. COULTER, C. R. BARNES, and J. C. ARTHUR, with American and foreign associates. Monthly; at least 80 pages. Devoted to the science of Botany in all its departments.

CONTENTS FOR DECEMBER 1898

The Affect of Aqueous Solutions upon the Germination of Fungus Spores — F. L. Stevens

The Physiological Action of Certain Plasmolyzing Agents — Rodney H. True

The Early Botanical Views of Prunus Domestica — F. A. Waugh

Briefer Articles: Recent Work Upon the Development of the Archegonium — Douglas Houghton Campbell
The Homology of the Blepharoplast — Charles J. Chamberlain

Open Letters: Another Question of Nomenclature — T. D. A. Cockerell

Current Literature—Book Reviews: The Organography of Plants — A New School Botany — Bokorny's Text-book
Minor Notices
Notes for Students

News.

$4.00 per year - - - 40 cents a copy

Address **The University of Chicago,**

The University Press Division, CHICAGO, ILL.

THE

JOURNAL OF GEOLOGY

The foremost journal of its kind. Open and comprehensive in its policy. Edited by T. C. Chamberlin and the Geological Faculty of the University of Chicago, assisted by representatives from the leading universities of the world. Issued semi-quarterly; $3.00 per year; 50 cents per number.

Vol. VI, No. 8, the November-December number contains:

Bowlder Pavement at Wilson, N. Y. — G. K. Gilbert

Geographical Relations of the Trias of California — James Perrin Smith

The Petrographical Province of Essex County, Mass. — Henry S. Washington

The Genetic Classification of Geological Phenomena — Charles R. Keyes

Studies for Students: The Development and Geological Relations of the Vertebrates—Parts IV and V, Aves and Mammalia — E. C. Case

Editorial

Summary of Current Pre-Cambrian Literature — C. K. Leith

Reviews

All subscriptions and requests for sample copies should be addressed to

THE UNIVERSITY OF CHICAGO,

UNIVERSITY PRESS DIVISION, Chicago, Ill.

Books of Continuing Value

MRS. LATIMER'S WORKS.

MY SCRAP BOOK OF THE FRENCH REVOLUTION

By ELIZABETH WORMELEY LATIMER. With numerous and carefully selected portraits of the principal personages of the time. 8vo, 442 pp. $2.50.

This is a graphic and thrilling account of some of the most exciting and interesting phases of the French Revolution. Much of the material is translated direct from original and recent French sources, not easily accessible to the ordinary student. The narratives of eyewitnesses and of actors and sufferers in the great drama are frequently quoted in detail.

Uniform with the above, and by the same author, are:

France in the 19th Century,	$2.50
England in the 19th Century,	2.50
Italy in the 19th Century,	2.50
Russia and Turkey in the 19th Century,	2.50
Europe in Africa in the 19th Century,	2.50
Spain in the 19th Century,	2.50

GROUND ARMS!

The Story of a Life. A Romance of European Wars. By BARONESS BERTHA VON SUTTNER. Translated from the German by ALICE ASBURY ABBOT. Fourth Edition. 12mo, $1.00.

"The most eloquent appeal for universal peace we have read in years. . . . The story is one of the strongest works of fiction of the present decade."—*The Arena.*

THE STORY OF LANGUAGE

By CHARLES WOODWARD HUTSON. 12mo, $1.50.

A GROUP OF FRENCH CRITICS

By MARY FISHER. 12mo, $1.25.

NATIONAL EPICS

By KATE MILNER RABB. 12mo, $1.50.

THE METHOD OF DARWIN

A Study in Scientific Method. By FRANK CRAMER. 12mo, $1.00.

LIFE OF ABRAHAM LINCOLN.

By the Hon. ISAAC N. ARNOLD. With an Introduction by the Hon. E. B. WASHBURNE. Steel portrait. 8vo, $1.50.

BISHOP SPALDING'S WORKS ON EDUCATION

By Rt. Rev. J. L. SPALDING, Bishop of Peoria.

"Bishop Spalding comes nearer being an essayist in education than any other American. He has that rarest of educational gifts—the ability to throw light brilliantly, and yet softly, making his paragraphs both bright and mellow, all without 'preaching,' without pedantry, and without being cranky. . . . When we agree with him it is delightful, and when we differ, we respect his convictions, honor his courage, and enjoy his spirit."—*Journal of Education*, Boston.

Thoughts and Theories of Life and Education, 12mo,	$1.00
Education and the Higher Life, 12mo,	1.00
Things of the Mind, 12mo,	1.00
Means and Ends of Education, 12mo,	1.00

PERSONAL SKETCHES OF RECENT AUTHORS

By HATTIE TYNG GRISWOLD. With a handsome and carefully selected portrait of each author. 12mo, $1.50.

Sympathetic and appreciative sketches on the following recent authors: Tennyson, Renan, Darwin, Matthew Arnold, Du Maurier, Mrs. Browning, Ruskin, Huxley, Mrs. Stowe, Stevenson, Howells, Louisa M. Alcott, Tolstoi, Kipling, Christina Rosetti, Thoreau, Bayard Taylor, Barrie.

By the same author and uniform with the above (but lacking portraits):

Home Life of Great Authors, 12mo, $1.50

THE LAW OF PSYCHIC PHENOMENA

By THOMSON JAY HUDSON. Fifteenth Edition. 12mo, $1.50.

A SCIENTIFIC DEMONSTRATION OF THE FUTURE LIFE

By THOMSON JAY HUDSON. 12mo, $1.50.

CHRISTIANITY; THE WORLD RELIGION

By Rev. JOHN HENRY BARROWS. Large 12mo, $1.50.

A WORLD PILGRIMAGE

By Rev. JOHN HENRY BARROWS. Crown 8vo, $2.00.

WITH A PESSIMIST IN SPAIN

By MARY F. NIXON. Illustrated. 12mo, $1.50.

AUDIENCES

A Few Suggestions to Those Who Look and Listen. By FLORENCE P. HOLDEN. Illustrated. 12mo, $1.00.

For sale by booksellers generally, or will be sent postpaid on receipt of price by the publishers.

A. C. McClurg & Co., Chicago

The University of Chicago Press Publications

ECONOMIC STUDIES

I. The Science of Finance.
An authorized translation of Gustav Cohn's "Finanzwissenschaft," by Dr. T. B. Veblen, of the University of Chicago. Large 8vo, cloth, xii+800 pages. Price $3.50 net.

II. History of the Union Pacific Railway.
By Henry Kirke White. Large 8vo, cloth, about 150 pages. Price $1.50 net.

III. The Indian Silver Currency.
By Karl Ellstaetter. Translated from the German by Professor J. Laurence Laughlin. Large 8vo, cloth, 132 pages Price $1.25 net.

IV. State Aid to Railways in Missouri.
By John W. Million, A.M. Large 8vo, cloth, 264 pages Price $1.75 net.

STUDIES IN POLITICAL SCIENCE

I. The Constitution of the Argentine Republic and the Constitution of the United States of Brazil.
Texts. By Elizabeth Wallace. Paper, 8vo, 96 pp., 50c net.
The texts are accompanied by a historical introduction, giving a brief review of the constitutional history of each country.

II. The Legal Nature of Corporations.
By Ernst Freund, J.U.D. Paper, 8vo, 83 pages, 50c.
This work contains a philosophic analysis of the legal concept, "Corporation." It is an important contribution to legal theory.

III. Early City Charters of Chicago.
By Edmund J. James, Professor in the University of Chicago. Paper, 8vo, 83 pages, 50c. (In press.)
The city of Chicago was under its early charters a council-ruled and council-organized municipality; the process by which it was slowly converted into the typical organization of today, with an independent and strongly organized executive, is reflected in the charters themselves.

GERMANIC STUDIES

I. Der Conjunktiv bei Hartmann von Aue.
By Starr Willard Cutting. Paper, 8vo, 54 pages, with 24 inserts of charts and tables, 50c.

II. 1. Verner's Law in Gothic. 2. The Reduplicating Verbs in Germanic.
By Frank Asbury Wood. Paper, 8vo, 44 pages, 50c.

III. Inedita des Heinrich Kaufringer.
By H. Schmidt-Wartenberg. Paper, 56 pages, 50c.

STUDIES IN ENGLISH

The Assembly of Gods: or, The Accord of Reason and Sensuality in the Fear of Death.
By John Lydgate. Edited by Oscar Lovell Triggs. Vol. I of the English Studies of the University of Chicago. Paper, large 8vo, 192 pages, $1.00 net.

The Treatment of Nature in English Poetry between Pope and Wordsworth.
By Myra Reynolds. Paper, 8vo, 280 pages, 75c. net.

Metaphor and Simile in the Minor Elizabethan Drama.
By Frederick Ives Carpenter. Paper, 8vo, 217 pages, 50c net.

MISCELLANEOUS

The Negatives of the Indo-European Languages.
By Frank Hamilton Fowler. Paper, large 8vo, 40 pages, 50c net.

The Evolution of the Classic Culture and Its Treatment.
By Thomas Fitz-Hugh. About 48 pages, 50c. (In press.) Paper.

Assyrian and Babylonian Letters belonging to the K Collection of the British Museum.
By Robert Francis Harper, Ph.D., of the University of Chicago.
I. Cloth, 8vo, xv+116 pages. Price $6.00.
II. Cloth, 8vo, 112 pages. Price $6.00.
III. Cloth (1896), 8vo, xv+116 pages. Price $6.00.
IV. Cloth (1896), 8vo, xvi+116 pages. Price $6.00.

Gold and Prices since 1873.
By J. Laurence Laughlin. Paper, 8vo, 66 pages, with charts, appendices, and bibliography. Price, 25c net.

SOCIOLOGICAL WORKS

An Analysis of the Social Structure of a Western Town.
By Arthur W. Dunn. Paper, large 8vo, 53 pages, 25c.

The Science of Sociology.
Supplementary to "The American Journal of Sociology." Paper, 67 pages. By James H. Hyslop, Ph.D., Professor of Logic and Ethics in Columbia University. 50c.

An Exposition in Outline of the Relation of Certain Economic Principles to Social Readjustment.
(In press.) By F. W. Sanders, about 64 pages, 50c. Paper.

The Sociologists' Point of View.
By Albion W. Small. Paper, 25 pages, 10c.

The Public Schools of Chicago.
In two parts. Part I: History. Part II: Structure and Functions of the School System. Paper, 50c.

HISTORICAL WORKS

The Development of the French Monarchy under Louis VI (Le Gros), 1108–1137.
By James Westfall Thompson. Paper, 8vo, 114 pages, $1.00 net.

Scutage and Knight Service in England.
By James Fosdick Baldwin. Paper, 119 pages, 50c.

Feudal Relations between the Crowns of England and Scotland under the Early Plantagenets.
By Charles Truman Wyckoff. 159 pages, 75c.

MISCELLANEOUS

Syntax of the Moods and Tenses in New Testament Greek.
By Ernest D. Burton, Head Professor of New Testament Literature and Exegesis in the University of Chicago. Second edition, revised and enlarged. Cloth, 12mo, xxii+215 pages. Price, $1.50 net.

The University of Chicago Contributions to Philosophy.
Each 35c; subscription to four numbers, $1.00. Paper.
I. Studies from the Psychological Laboratory. By James Rowland Angell. 52 pages.
II. The Necessary and the Contingent in the Aristotelian System. By Wm. Arthur Heidel, Ph.D.
III. Significance of the Problem of Knowledge. By John Dewey. 20 pages.
IV. Impersonal Judgment: Its Nature, Origin, and Significance. By Simon Fraser MacLennan. 49 pages.

Essays concerning Jesus and His Times.
Reprinted from Vols. IV, V, VI, and VIII of "The Biblical World." Cloth, $1.00.

Anthropological Bulletins.
Paper, 8vo, 25c each net.
I. Notes on Mexican Archæology. By Frederick Starr. 16 pages, with plates.
II. The Little Pottery Objects of Lake Chapala, Mexico. By Frederick Starr. 27 pages.

Studies in Classical Philology.
Boards, 8vo, 250 pages, $1.50 net. Contents of Vol. I:
I. The Anticipatory Subjunctive in Greek and Latin. By William Gardner Hale. Paper, 50c.
II. Vitruvius and the Greek Stage. By Edward Capps. Paper, 25c.
III. The Direction of Writing on Attic Vases. By Frank B. Tarbell.
IV. The Oscan-Umbrian Verb System. By Carl D. Buck. Paper, 50c.
V. The Idea of Good in Plato's Republic. By Paul Shorey. 25c.

Present Status of the Inquiry concerning the Genuineness of the Pauline Epistles.
By Bernhard Weiss, Theol.D., Professor in the University of Berlin. 78 pages, paper, 50c.

Physiological Archives.
Hull Physiological Laboratory. I. Publications of the year 1895. Paper, 8vo, $1.00 net. Edited by Jacques Loeb. All but one of the papers deal with problems of general and comparative physiology. Seven of the eight papers are in German. Illustrated.

Food as a Factor in Student Life.
By Ellen H. Richards and Marion Talbot. Paper, 8vo, 28 pages, 25c net.

Make remittances payable to
THE UNIVERSITY OF CHICAGO

The University of Chicago
The University Press Division **CHICAGO, ILL.**

Preliminary Table of Solar Spectrum Wave-Lengths

By Henry A. Rowland

PROFESSOR ROWLAND'S important TABLE OF SOLAR SPECTRUM WAVE-LENGTHS, which has been generally adopted by spectroscopists as the standard of reference, was first published in the *Astrophysical Journal*, beginning with Vol. I, No. 1, January 1895, and continuing to Vol. V, No. 3, March 1897. The Table gives the wave-lengths of nearly 20,000 lines, measured from photographs of the solar spectrum made with the concave grating at the Johns Hopkins University.

*** The eighteen separate parts, together with a table of corrections and additions, have been reprinted in a single volume of 225 pages, copies of which are now offered for sale at $1.50 each.

ALL ORDERS SHOULD BE ADDRESSED TO

The Press Division
The University of Chicago
Chicago, Ill.

Messages and Papers of

THE PRESIDENTS

A History of the

Written by Our Presidents

Edited by the

Hon. JAMES D. RICHARDSON,

Under the Direction of Congress.

To the American Citizen—The Father of the Future and Greater American:

In this Holiday season, when the whole nation is rejoicing over the outcome of the recent stirring events of our history, and congratulating itself on the final settlement in accordance with the American idea, it is well to think of the citizen that is to be, as well of him who is. Your boy should have a holiday gift to remind him for all time to come of what the American citizen of 1898 is, and what will be expected of the greater American citizen that is to be.

The great questions which confront us today are simple in comparison with those which will come up for solution, and the precedents of our past history are the guide posts for the future.

The greater American citizen must know more about American Statesmanship, American Genius, American Progress, American Institutions, and the inner workings of our American Government, past, present and future.

The Messages and Papers of the Presidents are the original sources for this education, and in these utterances are crystallized the wisdom and experience of our forefathers in history, and "History always repeats itself."

Congress had this in mind in authorizing the publication of this great work, and in appropriating the necessary amount to defray the initial expenses.

The Hon. AINSWORTH R. SPOFFORD, formerly Librarian of Congress, has accepted the position of General Secretary of the Committee appointed to distribute the work. If a private publisher were to undertake to publish it, even if he could gain access to the Government records, it would cost not less than a million dollars to produce, and he could not afford to sell it for less than Ten Dollars per volume. The Committee on Distribution has, however, undertaken to distribute the work at a trifle over the cost of manufacture and distribution. If it is necessary to increase the price to meet expenses, it will be done later, but not on applications received during month of December.

A postal card request for full particulars, addressed as below, will bring ample descriptive matter, full instructions for making applications, and several of the magnificent engravings contained in the work, suitable for framing, absolutely free.

On all requests accompanied by a deposit of ONE DOLLAR a set of the books will be laid aside and reserved pending further investigation, and if you decide within ten days not to make a regular application for the work, the amount will be refunded. All requests for further information will receive prompt attention, in regular order, if addressed to

AINSWORTH R. SPOFFORD, Gen'l Secretary, Committee on Distribution, Dept. S.
WASHINGTON, D. C.

The Pennoyer

KENOSHA
WISCONSIN

On Lake Michigan
50 miles from Chicago

The Ideal Resting Place

Established Forty Years

Combines in most perfect form the QUIET and Isolation of Country Life with the Luxuries of High-class Hotels, and the Safety of the best Medical Skill and Nursing

Elegantly illustrated descriptive pamphlet on application to

THE PENNOYER SANITARIUM CO.
KENOSHA, WISCONSIN.

HEALTH! REST! COMFORT!

The Jackson Sanatorium

Dansville, Livingston County, N. Y.

Established in 1858. Most beautiful and commodious Fire Proof Building in the world used as a Health Institution. All forms of Hydro-therapeutics, massage, rest cure; electricity administered by skilled attendants. A staff of regular physicians of large experience; accommodations and service of highest class. Superior cuisine directed by Emma P. Ewing, teacher of cooking at Chautauqua. Do not fail to write for illustrated literature and terms if seeking **health or rest.** Address

I. Arthur Jackson, M.D., Secretary, Box 2003.

"A PERFECT FOOD—as Wholesome as it is Delicious."

Walter Baker & Co.'s

Breakfast

Cocoa.

TRADE-MARK.

THE STANDARD FOR PURITY AND EXCELLENCE....

Costs less than one cent a cup

Our Trade-Mark on Every Package.

Walter Baker & Co. Ltd.

DORCHESTER, MASS.

ESTABLISHED 1780.

THE
SMITH PREMIER
THE MIGHTIEST WRITERS
are those who do the actual work in the vast correspondence of a nation. In this work one.....
SMITH PREMIER TYPEWRITER
is equal to scores of pens. The pen has given place to The Modern Writer, The Smith Premier, the machine typical of progress, the acknowledged leader in improvements.
SEND FOR CATALOGUE.
The Smith Premier Typewriter Co.,
SYRACUSE, N. Y., U. S. A.
THE MODERN WRITER

Huyler's

BONBONS, CHOCOLATES.

Always use the best.
The Best Pens are

ESTERBROOK'S

LEADING STYLES:

Fine Points, A 1, 128, 333.

Business Pens, 048, 14, 130.

Blunt Points, 122, 280, 1743.

Broad Points, 239, 313, 442.

Turned up Points, 256, 477, 531.

Vertical Writers, 556, 570, 621.

A GREAT VARIETY OF OTHER STYLES.

For Sale by all Stationers.

The Esterbrook Steel Pen Co.

Works, Camden, N. J. 26 John St. N. Y.

A PIANO

at a NOMINAL PRICE.

Chicago's largest music house, Lyon & Healy, to sharply reduce stock, offers sample new uprights, slightly used pianos, and second-hand instruments, at almost nominal prices. Good durable uprights as low as $100, warranted as represented. Square pianos $20 and upward. Grands from $200. Send for complete list. Among the makers are: Decker Bros., Hardman, Knabe, Steinway, Weber, Hale, Bauer, Fischer, Hazelton, and others. If you are interested in a piano, do not fail to write. Any piano not proving exactly as represented may be returned at their expense. Address

LYON & HEALY,

Wabash Ave. and Adams St., Chicago.

PAPER

In proportion as society refines, new books must ever become more necessary.
—Goldsmith.

As society refines, so also does it become more critical.

Lovers of Literature are Admirers of Art.

Papermaking is an art not learned in a day.

ESTABLISHED 1844.

J. W. BUTLER PAPER Co.
CHICAGO.

Chicago Office: 144 MADISON STREET

"PURE WATER Does Not Exist In Nature."

A radical statement, but authentic. To maintain normal conditions in the human body, there is absolutely required over three and one-half pounds of water daily, and less than two and one-half pounds of solid food. Water is found in every tissue and part of the body without exception. If it is *not pure* it defeats the purpose for which it is used. Absolutely pure water devoid of germs or inorganic salts is procured only through the process of distillation and

The Sanitary Still

Preeminently Leads!

Philippine Expedition Fully Equipped.
Only Still Recognized by U. S. Government.
Twelve Styles from which to Choose.
Double Capacity—Same Price.

The Sanitary Still fits on any wood, coal or gas stove. Simple as a tea kettle, easily cleaned, lasts a lifetime, produces pure, sparkling water at a cost of one to two cents a gallon.

Write for booklets containing letters from prominent bankers, physicians and pastors from every State in the Union and several foreign countries.

THE CUPRIGRAPH CO.,

109 North Green Street CHICAGO, ILL.

It Stands Alone

The secret of its supremacy over all similar foods rests in its superiority over them. Nothing but intrinsic merit could have forced it to so high a place in the world's esteem.

You are missing something good if you do not eat it.

THE EASY FOOD

Quaker Oats

THE WORLD'S BREAKFAST

ACCEPT NO SUBSTITUTE

8 BEAUTIFUL ETCHINGS

ILLUSTRATING AMERICAN SCENERY AND AMERICAN ACHIEVEMENT

☆ ☆ ☆ ON ☆ ☆ ☆

"AMERICA'S GREATEST RAILROAD"

An Illustrated Catalogue

Containing miniature reproductions will be sent free post paid on receipt of one 2 ct. stamp, by George H. Daniels, Gen'l. Pass'r. Agt. Grand Central Station, New York.

COPYRIGHT 1896, BY GEORGE H. DANIELS, GENERAL PASSENGER AGENT

NORTH & SOUTH

VIA THE

MONON ROUTE

DOMINION LINE

MAIL STEAMSHIPS

WEEKLY SAILINGS

MONTREAL AND QUEBEC TO LIVERPOOL

FORTNIGHTLY SAILINGS

BOSTON TO LIVERPOOL

VIA QUEENSTOWN

Large, fast, twin-screw passenger steamers Superior accommodation for all classes of passengers. The St. Lawrence route to Europe is yearly becoming more popular—the three days of smooth-water sailing after leaving Montreal, before the Atlantic is reached, being much enjoyed.

The sea passage is a short one of 1656 miles.

Boston as a port of departure for Europe is very convenient.

For all information as to rates, etc., apply to any local agent of the company, or

GUS BROBERG, 69 Dearborn St., Chicago.

Richards, Mills & Co., 103 State St., Boston, Mass. **David Torrance & Co., Gen. Agents, Montreal**

GRAND TRUNK RAILWAY SYSTEM

Grand Trunk

RY. SYSTEM,

THE FAVORITE ROUTE TO

All Canadian and Eastern Points

VIA THE "ST. CLAIR TUNNEL."

THROUGH SOLID VESTIBULED TRAIN SERVICE,

First- and Second-Class Coaches and Pullman Palace Sleeping Cars in connection with

THE LEHIGH VALLEY RAILROAD SYSTEM,

DAILY BETWEEN

CHICAGO and NEW YORK and PHILADELPHIA,

Via Niagara Falls and Buffalo.

Through Pullman Sleeping Car Service daily between Chicago, Detroit, Mt. Clemens, Saginaw Valley, Niagara Falls, Buffalo, Boston, Canadian and New England points via Montreal.

The Favorite Route for Summer Tourists, who should send their address to L. R. MORROW, Pass'r and Ticket Agent, Chicago, Ill., and ask for particulars regarding Summer Tours, Chicago to Niagara Falls, the Thousand Islands, the Adirondacks, the White Mountains, and the Summer Resorts of the Coast of Maine, which will be sent to all applicants free of charge. **Sale of Summer Tourist Tickets Commences June 1.**

For rates, Sleeping Car reservations, folders, etc., apply to

L. R. MORROW, CITY PASS'R & TKT. AGT.,
103 CLARK ST., CHICAGO, ILL

R. R. Donnelley & Sons Co.

The Lakeside Press

PRINTERS AND BINDERS

THE PRINTING OF BOOKS DEMANDING TASTE AND CAREFUL EXECUTION, PRIVATE EDITIONS, COLLEGE CATALOGUES, AND ANNUALS A SPECIALTY. WE PRINT MORE FINE BOOKS THAN ALL OTHER HOUSES WEST OF NEW YORK. OUR NEW FACTORY, RUN ENTIRELY BY ELECTRICITY, IS THE MOST ADVANCED PRINTING PLANT IN THE COUNTRY. THE LAKESIDE PRESS BLDG., PLYMOUTH PLACE, COR. POLK, CHICAGO.

... TEACHERS ...

Union Teachers' Agencies

of America. Rev. L. D. BASS, D.D., Manager.

Pittsburg, Pa., Toronto, New Orleans, New York, Washington, D.C., San Francisco, Chicago, St. Louis, Denver.
There are thousands of positions to be filled soon. We had over 8000 vacancies last season. More vacancies than teachers.
Address all applications to PITTSBURG, PA.

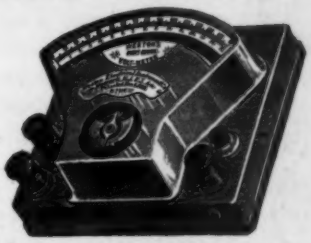
The University of Chicago

offers instruction by correspondence in many departments, including Political Economy, Literature, History, Mathematics, Languages, etc. Special circulars sent on application to
The University of Chicago,
Correspondence Study Dept., Chicago.

THE WESTON STANDARD

VOLTMETERS & AMMETERS

Portable,
Accurate,
Reliable and
Sensitive.



WESTON ELECTRICAL INST. CO.,
114 WILLIAM ST., NEWARK, N. J.

HAMMOND TYPEWRITER — FOR ALL NATIONS AND TONGUES

Every Clergyman and Every Public Speaker
should have
A Hammond Typewriter

The type intended for their special use gives perfect satisfaction. Type of another size or language is substituted in a moment by changing the shuttle. Send for new catalogue and enclose a 5c. stamp for a correct map of the world.

THE HAMMOND TYPEWRITER CO.,
403 & 405 East 62d St., New York

WHY IN THE WORLD doesn't a man like Jones get down to business methods when he can buy an American Typewriter for $10? Does he think I'm running a Puzzle Department?

THE AMERICAN TEN-DOLLAR TYPEWRITER is as well made as the highest priced machines, but more simple. It has stood the test of time. Five years without a competitor. 27,000 in use. Catalogue and sample of work free if you mention this magazine and address

THE AMERICAN TYPEWRITER CO.,
262 BROADWAY, NEW YORK.

The University of Chicago Press will furnish estimates on all kinds of printing—Books, Catalogues, Theses. Educational and scientific works printed in English, French, German, and all the other modern languages; also in Greek, Latin, Hebrew, Arabic, Ethiopic, and Nestorian Syriac. We carry full fonts of ancient and modern accents, many of which cannot be duplicated in any other institution in this country. Only high-grade work turned out. Address,

The University of Chicago Press, Chicago.

Lakeside Hospital

(Incorporated 1884)

4147 Lake Avenue, Chicago

Built expressly for the purpose after many years of hospital experience. Forty private rooms of the very first class. Equipped for the care of the sick in a manner not attainable in any home, private residence or hotel.

Non-contagious medical and surgical cases of all kinds admitted. Special provision has been made for obstetrical cases.

Nurses furnished to physicians or private families either in the city or country at any time.

Special Terms to University Students

Nelson H. Henderson, M. D.

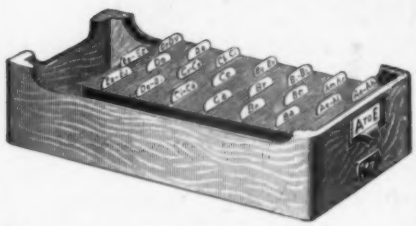
Proprietor and Physician and Surgeon in charge, with associated staff.

Telephone Oakland 221

Globe Goods are Good Goods.

A Business Man's Time

IS WORTH money; it has a market value. Anything that will economize that time is eagerly sought after.



The Globe Card Index File

is a labor-lessener—a ready reference of information regarding any detail of your business.

Alphabetical arrangement of any necessary information always at your elbow—that's just what the Globe Card Index secures. . . . Illustrated catalogue free. . . .

THE GLOBE COMPANY,

226-228 Wabash Ave., CHICAGO. **1224-1248 W. Eighth St., CINCINNATI.** **Fulton & Pearl Sts., NEW YORK.**

BINNER ENGRAVING CO.

FISHER BUILDING
CHICAGO

PHOTOGRAPHIC and Lantern Slide Apparatus and Materials for the Scientist and Amateur

Anthony's Micrographic Camera
Anthony's Lantern Slide Camera
A. T. Thompson & Co's Improved Electric and Lime Light Stereopticons.
Hand Cameras and Outfits of all kinds.
Tripod Cameras, Lenses, Shutters, New American Films, Dry Plates, Developers, Chemicals, Flash-light Apparatus, American Aristotype and American Gelatine Papers, and everything requisite for either Amateur or Professional.

Books of Instruction

for the beginner or advanced worker.
Send for Booklets or Catalogue.

E. & H. T. ANTHONY & CO.

591 Broadway, New York
45, 47, 49 E. Randolph St., Chicago

THE JOINTLESS, LUCKY CURVE GEO. S. PARKER FOUNTAIN PEN

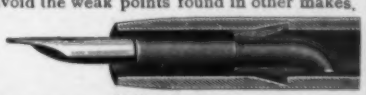
THE SUCCESS OF THE PEN AGE.

The greatest improvement ever made in fountain pen construction.

NO SCREW TO BREAK. NO NOZZLE TO GET "STUCK." NO JOINT TO LEAK. PERFECTION.

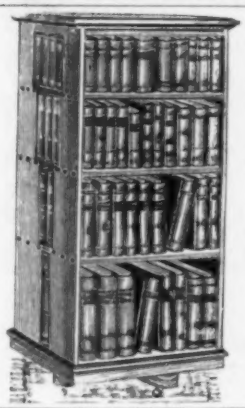
To those who have never owned a Fountain Pen, the "PARKER" is a DELIGHT—to those who have tried others it is PERFECTION. First right in principle, then skillfully made to avoid the weak points found in other makes, Parker Pens seem to "go alone," so smooth and easy is the movement.

For sale by bright dealers everywhere. If the dealer of whom you inquire does not keep the "PARKER," and tries to sell you a "just as good," he is either honest in his ignorance, or trying to deceive you. If he will not supply you, we will. *Interesting Booklet Free.*



SECTIONAL VIEW.

The PARKER PEN COMPANY, 34 Mill St., Janesville, Wis.
The largest bona fide manufacturers of Fountain Pens in the world.



Sargent's Economic System

OF DEVICES FOR
BRAIN WORKERS

Embraces all the survivals of the fittest, including

Sargent's Ball Bearing Rotary Book Cases,
Sargent's Reading Stands in various styles,
Sargent's Dictionary and Atlas Stand,
Sargent's Desks, attachable to chairs,
Sargent's Telescopic Book Racks,
Sargent's Adjustable Folio Stands, and
SARGENT'S WORKING, EASY RECLINING, LIBRARY AND ADJUSTABLE CHAIRS, COUCHES, ETC.

For catalogue, address

GEO. F. SARGENT COMPANY,

289 n Fourth Avenue, next 23d, NEW YORK CITY.

The Greatest Historical Work of the Century.

History for Ready Reference and Topical Reading.

In Five Imperial Volumes.

By J. N. LARNED,

Ex-Pres. American Library Ass'n.

This work is in itself a ***complete Historical Library.*** The fruit of the ripest scholarship has been gathered upon thousands of topics, from thousands of volumes.

A ***complete system*** is given to ***History,*** presenting its topics in their ***sequence*** and ***inter-relations,*** most convenient for reading, for study, or for reference.

The time ordinarily spent in seeking accurate historical information is, by this work, saved by the many years of laborious research and discriminating thought expended in its preparation. It makes one acquainted not only with ***History*** but with ***Historians.***

Nothing like it has ever been attempted, and, in the opinions of the most distinguished literary men of all professions, it is the ***greatest Historical Work of the Century.***

These opinions, with full information, sent on application. Sold only by subscription, and sent, carriage free, to responsible subscribers on easy payments.

*** ***Experienced Solicitors Wanted.***

Address the Publishers,

The C. A. NICHOLS CO.,

Springfield, Mass. ***Chicago, Ills.***

The History for Ready Reference is an important work, representing both History and Literature. It furnishes a consensus of opinion of the best historians upon great historical questions and the reduction to a system of the great body of History as presented in thousands of volumes. The use of these volumes must prove an inspiration, whether in the family, in the study, in the office, or in the school.

WILLIAM R. HARPER, President,
Chicago University.

THE

Morgan Park Academy of The University of Chicago

A thorough Preparatory School for both sexes. Twelve Teachers, all specialists and college graduates. Eight buildings, Athletic Field, Gymnasium. Library of 4000 volumes. Delightful situation; near enough to the city for Chicago students to spend Saturday and Sunday home. Preparation for The University of Chicago and all other Colleges and Universities. Life in houses under Teachers' supervision. Introductory year for young pupils. For Calendar and full information address the Dean of the Academy, MORGAN PARK, ILL.

THE PHILOSOPHY OF THE HUMANITIES. By THOMAS FITZ-HUGH, Professor of Latin in the Univ. of Texas.

Une éloquente démonstration de la nécessité qu'il y a pour une nation, non pas à savoir, mais à avoir appris le latin.—*Le Temps.*

The work is scholarly and instructive and will be studied with interest and profit.—*Journal of Education*, Boston.

Brief, lucid, convincing, it must inevitably mark an era in scholastic practice all over this country.—*Alcalde*, Austin, Tex.

A sturdy advocate of the study of Latin.—*Pop. Sci. Monthly.*

63 pp. 50c. The University of Chicago Press, Chicago, Ill.

JUST PUBLISHED. PRICE TWELVE CENTS

The Natural History and Scientific Book Circular
Nos. 129, 130

MATHEMATICAL AND PHYSICAL SCIENCES

Including Works from the Libraries of
REV. A. FREEMAN, M.A., F.R.A.S., A. MARTH, F.R.A.S., and J. R. HIND, F.R.A.S., Late Superintendent of the Nautical Almanac Office, London.

Containing 3000 works (96 pages), including works on the Spectrum, Telescope, Eclipses, Comets, Meteors. To be had on application to

WILLIAM WESLEY & SON,

Agency of the Smithsonian Institution
U. S. Government Departments,

28 ESSEX STREET, STRAND, LONDON.

A WONDERFUL MEDICINE

BEECHAM'S PILLS

For Bilious and Nervous disorders such as Wind and Pain in the Stomach, Sick Headache, Giddiness, Fullness and Swelling after meals, Dizziness and Drowsiness, Cold Chills, Flushings of Heat, Loss of Appetite, Shortness of Breath, Costiveness, Blotches on the Skin, Disturbed Sleep, Frightful Dreams, and all Nervous and Trembling Sensations, etc., when these symptoms are caused by constipation, as most of them are. **The first dose will give relief in twenty minutes.**

This is no fiction. Every sufferer is earnestly invited to try one box of these Pills, and **they will be acknowledged to be a wonderful medicine.** BEECHAM'S PILLS, taken as directed, will quickly restore females to complete health. They promptly remove obstructions or irregularities of the system.

For a Weak Stomach, Impaired Digestion, Disordered Liver, Sick Headache, Female Ailments

they act like magic—a few doses will work wonders upon the vital organs: strengthening the muscular system, restoring the long-lost complexion, bringing back the keen edge of appetite, and arousing with the **Rosebud of Health the whole physical energy** of the human frame. These are facts admitted by thousands in all classes of society, and one of the best guarantees to the Nervous and Debilitated is that **Beecham's Pills have the Largest Sale of any Patent Medicine in the World.**

25 CENTS AT DRUG STORES.

Without a Rival. Annual Sales Over 6,000,000 Boxes

ALVAN CLARK & SONS

CAMBRIDGEPORT, MASS.

Manufacturers of

ASTRONOMICAL TELESCOPES

With Improved Equatorial Mountings

Sizes from Four-inch Aperture
to the Largest Ever Ordered

Send for Photographs of our Portable Equatorials or five and six-inch fixed, with accessories — the best to be had for educational and amateur work.

Terrestrial Telescopes for private residences

The performance of our instruments, famous the world over, is their own greatest recommendation. An experience of nearly a half century in the art of telescope making enables us to apply a degree of skill and judgment to our work which make our objectives **unrivalled in excellence.**

Among our telescopes are

The Lick Refractor, 36-inch.
Pulkowa Refractor, 30-inch.
Washington Refractor, 26-inch.
University of Virginia, 26-inch.
Princeton Refractor, 23-inch.
Denver Refractor, 20-inch.
Chicago Refractor, 18.5-inch.
Rochester Refractor, 16-inch.

WHAT IS

POND'S EXTRACT?

A Family Remedy which, for over 50 years, has stood the test of time.

INVALUABLE FOR ALL ACHES, PAINS, INFLAMMATIONS, CATARRHAL TROUBLE AND PILES.

GET THE GENUINE. AVOID IMITATIONS.

POND'S EXTRACT CO., New York and London.

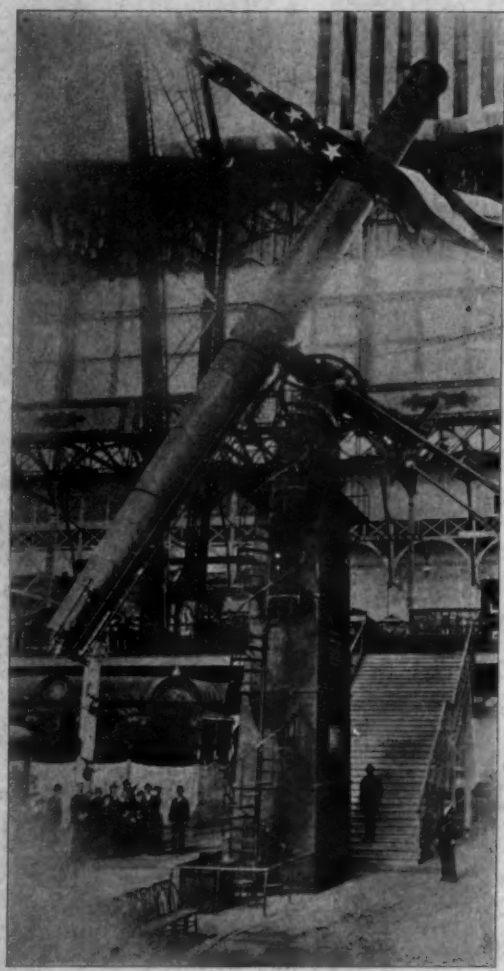
Rest comes often

to users of

SAPOLIO.

It drives dirt forth and lets light and brightness into the house

Astronomical Instruments



40-in. Yerkes Telescope at Columbian Exposition

Equatorial Telescopes

Zenith Telescopes

Alt-Azimuth Telescopes

Meridian Circles

Transits

Chronographs

We have in process of construction a complete line of standard telescopes for educational institutions and private observatories.

WARNER & SWASEY

CLEVELAND, OHIO, U. S. A.